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HANDBOOK OF ELECTRICAL INSULATING MATERIALS FOR DEEP-OCEAN APPLICATIONS

**DEEP OCEAN TECHNOLOGY PROGRAM
DAVID W. TAYLOR NAVAL SHIP
RESEARCH AND DEVELOPMENT CENTER
ANNAPOLIS, MARYLAND 21402**

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The critical factors involved in the selection of electrical insulating materials for deep ocean equipment are defined, and methods are presented for determining compatibility of electrical insulating materials under deep ocean application conditions. The values of critical properties of typical electrical insulating materials are given as they have been determined or are known

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Abstract (Cont)

from previous literature.   Suggestions are also given on the applicability of typical electrical insulating materials for deep submergence applications.   It is planned to revise and update the contents of this handbook periodically.

                                    (Authors)

ADMINISTRATIVE INFORMATION

ACKNOWLEDGMENTS

LIST OF ABBREVIATIONS

°F	- degrees Fahrenheit
°C	- degrees Celsius
d-c	- direct-current
a-c	- alternating current
psi	- pounds per square inch
e.g.	- for example
DSVs	- deep-submergence vehicles
cSt	- centistoke
cm^3	- cubic centimeter
mm	- millimeter
kv	- kilovolt
wt	- weight
psig	- pounds per square inch gage
etc.	- and so foith
No.	- number
OVMG	- organic (nonsilicone) varnish-mica-glass
SVMG	- silicone varnish-mica-glass
DOT	- deep ocean technology
Hz	- hertz
mA	- milliampere
in.	- inch
mg	- milligram
LOSS	- lost object salvage system
hp	- horsepower
AWG	- American Wire Gage

FOREWORD

The Naval Sea Systems Command is engaged in continuing development of the necessary technology base from which future Navy ocean engineering systems can draw. This ocean engineering handbook is one of a series pertaining to deep ocean systems resulting from work in support of the objectives of the U. S. Navy's Deep Ocean Technology Program.

The ocean engineering handbooks document pertinent available information and technical data and are reviewed and updated periodically. They are intended to serve as guides for naval designers, engineers, and operating personnel concerned with systems which will operate in the deep ocean environment and as references for Navy education and training in this area.

Questions or comments concerning the handbooks are welcome and should be addressed to the Commander, Naval Sea Systems Command (Attention: SEA 0353).

PREFACE

The DOT "Handbook of Electrical Insulating Materials for Deep Ocean Applications" was prepared to provide critical properties, evaluation methods, and other pertinent electrical insulating material information to designers, engineers, and operating personnel concerned with deep ocean applications.

This handbook is a guide, not a specification. It cannot be cited as authority for action. It supplements published information and aids the user in the selection of electrical insulating materials suitable for a particular deep ocean application.

CONTENT AND ORGANIZATION OF THE HANDBOOK

Chapter I defines the environment, describes and compares the methods of protecting electrical circuits from the deep ocean environment, and summarizes basic principles relating to the design of insulating systems for use in pressure-compensating fluids.

Chapter II provides a description of typical electrical insulating materials, including the nature of the materials and how they are used in the pressure-compensating fluid environment in terms of the considerations of Chapter I.

Chapter III discusses the application of electrical insulating materials to the design of specific devices for fluid-compensated systems making use of the information of Chapters I and II.

Chapter IV describes in detail the evaluation methods used to determine the compatibility of materials in fluid-compensated systems subjected to deep ocean pressures.

Chapter V presents the properties of materials as determined by the procedures of Chapter IV along with limitations on physical characteristics of each material.

In compiling these data we have consulted many sources and utilized applicable experience wherever found. Thus, the Bibliography (appendix A) represents, in effect, contributors as well as source material.

REVISIONS, GROWTH, AND "USER COMMENT RETURN FORM"

The DOT "Handbook of Electrical Insulating Materials for Deep Ocean Applications" is designed to be revised periodically to include new data and considerations for fluid-encapsulated system design and additional deep ocean applications. Responsibility for the maintenance and expansion of the handbook has been assigned, under the supervision of the Commander, Naval Sea Systems Command (SEA 03531), to this Center.

Revisions to the handbook will be effected by the use of page changes and additions. As the handbook is published in loose-leaf form revisions may easily be made.

User commands and individuals within the Navy and the non-military marine community are encouraged to submit additional data, paragraphs, or chapters. Less extensive feedback, even mere indications that specified sections are judged to be too general, is useful and solicited. Feedback may be forwarded directly to:

> Deep Ocean Technology Program
> David W. Taylor Naval Ship R&D Center
> Annapolis, Maryland 21402

Material received will be carefully reviewed and coordinated prior to publication. A preaddressed user comment return form is included for your convenience.

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INTRODUCTION

In the typical U. S. Navy submarine most of the operating machinery for propulsion, maneuvering, and other required functions is located within the pressure hull. In contrast, only the control equipment of most deep-submergence vehicles is housed within the pressure capsule. Connections are made to external machinery by means of specially designed hull penetrators which provide sealing against the external ocean and electrical insulation from the hull. Electrical connections are made through metal pins which are commonly sealed into the penetrator body by metal-to-glass seals. Thus, only electrical control signals are provided to pumps, motors, winches, hydraulic systems, and other required machinery operating in the ambient pressure, temperature, and contaminating environment of the deep ocean.

To shield system components from the corrosive action of seawater and other effects of the ocean environment requires that equipm. it be operated within some sort of protective medium. There a three possible approaches to the solution of this problem, nd they are described and compared in Chapter I. This handbook is concerned primarily with only one of these, the pressure-compensated system approach. This approach requires that electrical equipment, including batteries, drive motors, and circuit-interrupting devices operate immersed in organic liquids which potentially can chemically attack insulating materials and cause them to deteriorate. Since there was little or no published reliable data available on the effects of pressure-compensating fluids on specific insulations, and especially not at high pressures, it was necessary to obtain such data. This Center, funded by NAVSEA (SEA 0353) (then NAVSHIPS, SHIPS 03424), under the Navy's Deep Ocean Technology Program, undertook to obtain data in a project that lasted well over 2 years. Special high-pressure equipment was set up that could be used for evaluating the effects of pressure-compensating fluids on insulating materials at pressures from 0 to 13,200 psig (equivalent to an ocean depth of 29,000 feet) and temperatures from 25° to 90° C. Available insulating materials were surveyed and certain types were selected that both covered the range of insulations needed and seemed at the same time to have a good possibility of being compatible with pressure-compensating fluids. The selected materials were then evaluated. The results of these evaluations, the most important part of this handbook, are summarized in Chapter V in the form of data tables and "application guides". There is no claim for completeness in this information, and it is hoped that it can be supplemented as time passes.

CHAPTER I

DESIGN CONSIDERATIONS IN DEEP OCEAN
APPLICATIONS OF INSULATING MATERIALS

1.1 APPROACHES TO THE PROTECTION OF ELECTRICAL EQUIPMENT
     EXTERNAL TO PERSONNEL CAPSULE

The deep ocean environment has created problems in the use
of materials for which no precedents exist. Materials are
required to perform under adverse conditions in which they must
withstand an ambient temperature that can range from 28° to 130°
F* and ambient pressure to 15,000 psi. Since the operating
equipment, except for control systems, of most deep submersibles
is housed external to the personnel pressure capsule, operating
components must be protected from direct contact with the sea-
water. There are three possible approaches to providing this
protection:

- Encapsulation.

- Hard-shell enclosure.

- Pressure compensation.

Encapsulation involves completely embedding the item to be
protected in, or surrounding it with, a plastic material such as
an epoxy resin. This technique has found only very minor use
in deep-submergence practice because of a number of serious limi-
tations:

- It cannot be used for equipment having moving parts
with exposed conducting surfaces.

- Failed units cannot be readily repaired.

- Encapsulants have poor heat-transfer properties
which means possible problems in the dissipation of I^2R heat.

- There is the possibility of seawater penetration
which may cause cracking or separation of the encapsulant.

Hard-shell enclosure is the placing of equipment in air or
an inert gas at atmospheric pressure inside a pressure-resistant
casing. This also has a number of limitations:

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*Definitions of abbreviations used are on page i.

- The virtual impossibility, using technology developed to date, of sealing rotating motor shafts where they penetrate the casing or hard-shell wall.

- The large size and weight of the hard-shell necessary to withstand the high external pressure.

- Poor heat transfer from components in the hard shell if insulated from the shell.

- Entrapment of gaseous decomposition products from insulation and other organic materials which may cause corrosion or may further accelerate decomposition of insulating materials.

Pressure compensation means immersing equipment in a liquid known as a pressure-compensating fluid inside a thin-walled enclosure. The major limitations of this approach fall into three categories:

- Possible incompatibilities between the fluid and electrical insulation (as well as other organic materials such as gasketing).

- Problems caused by carbon generation in the liquid.

- The inconvenience of handling liquids.

1.2 PROTECTION OF INDUCTION MOTORS BY "CANNING" (SEAWATER FLOODED MOTORS)

A technique successfully applied to a-c induction propulsion motors is that of "canning". The stator windings are enclosed by the motor housing and end rings to which are welded a metal liner fitted snugly to the internal bore of the stator. The stator is thus entirely surrounded by a protective metal envelope or "can". The internal voids are filled in one of three ways:

- **With Dry Nitrogen.** In this case the metal envelope must be strong enough to withstand the external ocean pressure. This is a type of hard-shell enclosure, and conventional insulation methods are used.

- **With Epoxy Resin.** This is similar to encapsulation except that the epoxy is only a filler and is not relied on for ultimate protection of the windings.

I-2

• <u>With Oil or an Oil Slurry</u>. This involves the same problems for insulating materials as immersion in fluids in pressure-compensated systems.

The rotor may be similarly canned (but without the problem of filling in voids); coated with epoxy resin (bonded rotor); or coated with a phenolic material. The bearings of this type of motor are usually water lubricated. The entire motor is then operated free-flooded in the ocean environment. All exposed metal parts must of course be resistant to seawater corrosion. For further descriptions of seawater flooded motors see the Handbook of Electrical Drive Systems for Deep Ocean Application,[1] Section 2, 2.3.3.2.

1.3 PREDOMINANCE OF THE PRESSURE-COMPENSATION APPROACH

Pressure compensation is the only satisfactory method under present technology for housing d-c or a-c propulsion motors, other than induction motors, external to the personnel pressure capsule of deep submersibles. It can also be used satisfactorily for housing other equipment such as circuit interrupters and batteries. In general, this technique is free from the major disadvantages of hard-shell enclosures. While it has its own limitations, pressure compensation has become the most extensively used of the possible methods previously discussed for protecting equipment from the ocean environment. For a detailed comparison of pressure compensation with the other approaches, see the DOT pressure-compensated systems handbook,[2] pages XII-XIII. This handbook has been compiled primarily from the standpoint of electrical insulation requirements peculiar to operation in pressure-compensating fluids.

1.4 FURTHER DESCRIPTION OF PRESSURE COMPENSATION

A pressure-compensated system consists of the thin-walled enclosure housing the equipment it is protecting, filled with a liquid, and provided with a means such as a bladder or diaphragm to allow for compression of the fluid under the high pressure of the ocean when diving to great depths and subsequent reexpansion on surfacing. In order for the pressure-compensated system to function correctly, the fluid must fill all open spaces in the enclosure including those in the immersed equipment itself. In this way the external ocean pressure is transmitted equally throughout all parts of the system. There is essentially zero pressure differential from one part of the enclosure to another.

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[1] Superscripts refer to similarly numbered entries in the Technical References on page V-32.

as well as across the walls of the enclosure. However, a small positive pressure differential may be maintained within the enclosure, over the outside ocean pressure, to prevent or minimize leakage of ocean water through the seals into the pressure-compensating fluid. A detailed description of pressure compensated systems will be found in the DOT pressure-compensated systems handbook.[2]

1.5 ASPECTS OF PRESSURE COMPENSATION RELEVANT TO ELECTRICAL INSULATION

1.5.1 Pressure-Compensating Fluid

The property requirements for a liquid in which electrical equipment is to operate are fairly clearly defined as follows:

- Dielectric properties must be acceptably high.

- Lubricity must be acceptable when the fluid is used with electric motors.

- Viscosity should be low enough that fluid frictional losses are not excessive.

- Specific gravity should be as low as possible in keeping with other requirements and preferably have a value less than 1.

- Electrical arcing in the fluid should not produce noxious compounds such as HCl or HF.

Compensating fluids in use at present are petroleum-base and silicone liquids which have a range of properties meeting these property requirements to varying degrees. Most of the required properties mentioned here, and others, are elaborated on more fully in the DOT fluids handbook.[3]

1.5.2 Properties of Compensating Fluids Advantageous to Insulation

It was stated in paragraph 1.3 that the pressure-compensation technique is free of the major limitations of hard-shell enclosures. The DOT pressure-compensated systems handbook[2] provides a detailed comparison of the two approaches in general. The following three paragraphs point out several advantages of compensating fluids relating specifically to electrical insulation.

1.5.2.1 Heat Transfer

Because of the superior heat-transfer properties of liquids over those of air the removal of I^2R heat from electrical equipment operating in compensating fluids is much faster than in air environments. (See DSSV Engineering Report,[4] pages 3-3 to 3-6). Consequently, electrical components for use in fluids can be made smaller for a given value of current to be carried than they are for air operation. In actual practice at the present time this principle is not being exploited as fully as it might be, especially in the use of off-the-shelf components such as mechanical contactors and circuit breakers. Such items are usually assigned the same current rating for use in fluids as they are originally designed for in air. However, this means that since I^2R heat is dissipated more readily, insulating materials do not reach as high a temperature as in air. Thermal degradation will therefore be less of a problem. Propulsion motors, which are usually specially designed and built for operation in pressure-compensating fluids, are in many cases designed closer to optimum size in this respect.

1.5.2.2 Exclusion of Oxygen

Since the concentration of dissolved oxygen in liquids is much lower than in a normal air environment, and since depleted oxygen is not readily replenished (except in battery compartments during recharging) as it is in the normal air atmosphere, there is less tendency toward oxidative deterioration of insulation in compensating fluids than in air.

1.5.2.3 Dielectric Properties

Compensating fluids are markedly superior to air in dielectric breakdown voltage, i.e., the electrical potential difference required across a given spacing for arcing to occur. This holds true with small amounts of carbon present in suspension of the order of 0.01 to 0.1 gram per 100 cm^3 of fluid (see data in table I-1) and/or small quantities of emulsified seawater, possibly between 0.1 and 1.0% by volume. At higher concentrations of these contaminants, the breakdown voltage approaches and may become less than that of air. In practice, the breakdown voltage of pressure-compensating fluids in which electrical devices operate tends to remain well above that of air because of monitoring procedures described further on (see 1.5.3.4.3). The resistivity of uncontaminated compensating fluids is generally lower than that of air but is not affected by carbon or emulsified seawater to the same extent as is breakdown voltage (see table I-1).

The effect of carbon on dielectric properties of fluids is discussed further in paragraph 1.5.3.4.2.

TABLE I-1*
EFFECT OF SUSPENDED, FINELY DIVIDED CARBON
ON DIELECTRIC PROPERTIES OF TWO PRESSURE-
COMPENSATING FLUIDS

Properties	New Fluid	Fluid with Carbon Added Grams per 100 cm^3		
		0.01	0.10	0.50
MIL-H-5606B Fluid				
Electrical resistivity, ohm-cm	2.4×10^{12}	2.3×10^{12}	2.1×10^{12}	6.8×10^{9}
Dielectric breakdown voltage, kilovolts for 0.05-inch gap	25.1	14.5	<3.0	<1.0
MIL-H-6083C Fluid				
Electrical resistivity, ohm-cm	3.1×10^{10}	2.4×10^{10}	1.9×10^{10}	1.7×10^{10}
Dielectric breakdown voltage, kilovolts, across 0.05-inch gap	25.5	13.8	<6.0	<2.0

*Handbook of Fluids and Lubricants for Deep Ocean Applications[3] pages III-28, -29, -45, and -46.

1.5.3 Problem Areas

1.5.3.1 Compatibility of Insulation with Fluids

Insulations used on deep-submergence vehicles and systems are composed partly or entirely of organic materials such as magnet wire film insulation, varnishes, and various other synthetic polymer products. These materials are subject to attack by organic liquids with possible loss of their dielectric protective value. Inorganic materials such as glass and mica are not so affected.

Figure I-1 shows an example of a particularly severe effect of a pressure-compensating fluid on an insulating material. The silicone resin impregnant was sufficiently softened by Code E compensating fluid[3] in only 250 hours of operation, at a maximum fluid temperature of 140° F (60° C), to cause extensive fraying. The glass tape, while not directly affected by the fluid, loses its physical integrity. In the development

of pressure-compensated systems to date, liquids such as toluene
and xylene, which are notorious in their effect on many poly-
meric materials, have been avoided. However, those fluids that
have come into use represent generally a compromise between
many desired properties, and compatibility between insulations
and fluids is still a potential problem area. Choosing insulating
materials is one of the most important aspects of selecting or
designing electrical equipment to be used in pressure-compensated
systems. Chapter V provides extensive data for this purpose.
It will be seen in the tables in Chapter V that materials falling
into the categories of polyamides, polyimides, polyesters, and
fluorocarbons tended to be the least affected by compensating
fluids, while polyvinyl chloride, neoprene, and silicone rubber
tended to deteriorate most readily. Caution should be exercised
in choosing insulations on the basis of broad chemical types,
however, since materials so chosen could be significantly dif-
ferent from the specific materials evaluated and reported on in
the tables.
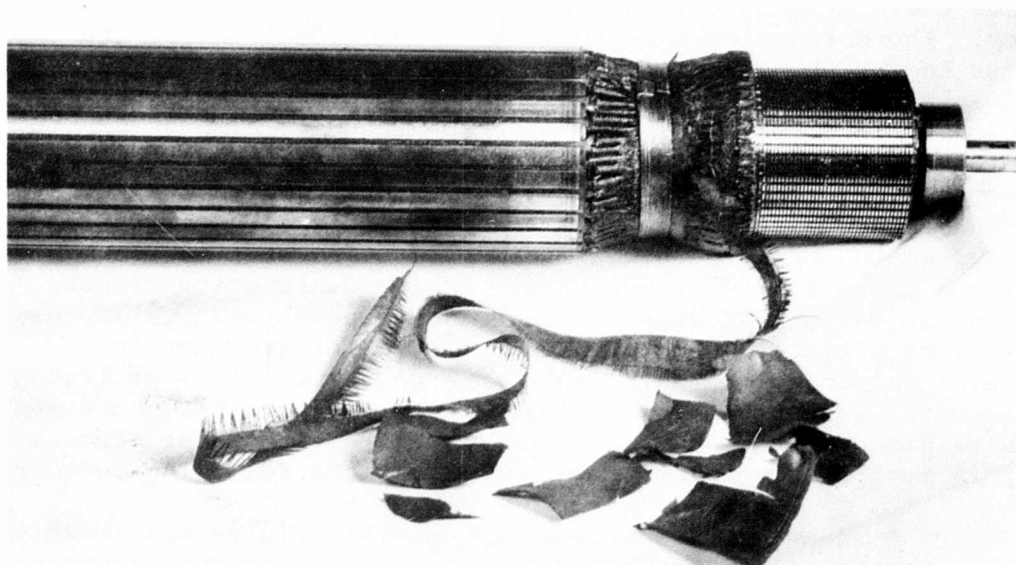
Figure I-1
Rotor of 7½ HP D-C Motor Showing Fraying
of Resin-Impregnated Woven Glass Tape
(Compare Item (b), Figure III-4, Chapter
III, in Which Glass Tape Has Been
Replaced by Polytetrafluorethylene Sleeve)

1.5.3.2 Effect of Temperature on Materials-Fluids Compatibility

The effect of temperature on the tendency of compensating fluids to attack insulations can be seen in the data tables of Chapter V. As expected, it is much greater at 90° than at 25° C. Certain materials are considered acceptable in those applications in which the amount of heat generated is low enough that temperature does not rise significantly above 25° C. Fluid temperature is important also in relation to hydrolytic stability which is discussed in the following paragraph.

1.5.3.3 Possible Damage to Insulating Materials by Hydrolysis

Certain types of organic compounds tend to undergo hydrolysis, i.e., chemical decomposition by reaction with water. Several types of polymeric materials used for insulation notably polyvinyl formal, polyesters, polyimides, and polyamides are known to hydrolyze to some extent, the rate of hydrolysis varying from one polymer to another. This could result in a reduction in physical strength and insulating quality if external seawater leaks into the pressure-compensated system. However, the hydrolysis rate of any of these materials is appreciable only at elevated temperatures. The discussion that follows is intended to alert the reader to the phenomenon of hydrolysis as a potential rather than an actual problem since it has not been reported as a known difficulty in deep-submergence practice to date.

Table I-2 shows the effect of straight steam at 122°/132° C on four magnet wire insulations and one varnish. According to Lipsey, quoted by Halpern,[5] a minimum of 0.7% water in transformer oils at 125° C is equivalent in its destructive effect on insulation to 100% steam at the same temperature. This relationship is believed to hold true also for seawater in pressure compensating fluids so that even a small rate of leakage of seawater may be harmful to insulations if the fluid temperature is high enough. Damage by hydrolysis, if it takes place at all, is most likely to occur in motors for the following reasons:

• Seawater leaks into compensating fluids most readily through rotating shaft seals. Although sealing is very much less of a problem with pressure-compensated systems than with hard-shell enclosures, leakage is not entirely eliminated. (Since propulsion motors commonly are separately pressure-compensated, the leaked-in seawater is confined to the motor enclosure.)

• A number of insulations used in motors, primarily magnet wire film and varnishes, as listed in table I-2, are of the chemical types that are subject to hydrolysis.

• Temperatures within motor compartments tend to be higher than in other pressure-compensated enclosures because of fluid frictional heating in addition to I^2R losses.

TABLE I-2
HYDROLYTIC STABILITY OF MAGNET WIRE FILM
INSULATION AND VARNISH*

Material	Chemical Type	Hours in Steam at Indicated Temperature, to Dielectric Failure
Magnet Wire Films		
Code A, heavy coating	Polyvinylformal	65 at 122° C (15 psig)
Code B, heavy coating	Polyimide	103 at 122° C (15 psig)
Code D, heavy coating	Polyamide-imide coated polyester	83 at 132° C (25 psig)
Code E	Polyamide-imide	703 at 132° C (25 psig) Note: As of date of publication of handbook, this material may no longer be commercially available.
Varnish		
Code G, over Code B magnet wire film	Polyester	197 at 132° C (25 psig)

*See table 1 in both technical references 5 and 6.

Temperature is extremely important since the rate of hydrolysis decreases logarithmically with decreasing temperature. An accurate knowledge of actual operating temperature limits within pressure-compensated systems on working submersibles would therefore help to answer the question of how much of a possible problem hydrolysis actually is when seawater is present. Unfortunately, there is very little such information available at present although indications are that maximum operating temperatures are usually below 93° C (200° F). In 100% water at the indicated probable upper limit of 93° C the insulation life of Code B magnet wire film (the preferred magnet wire

insulation, per table V-2, Chapter V) has been estimated* to be about 16 times that shown in table I-2, i.e.; about 1700 hours or 10 weeks. At a temperature of 80° C (176° F) it was estimated to be about 10,000 hours or 1.1 years. These figures are consistent with the absence to date of reported insulation failure on operating submersibles attributable to hydrolysis. In one case, that of insulation failure on 3-phase a-c propulsion motors on the DSRV's 1 and 2, hydrolysis was considered as a possible contributing cause. However, there may also have been excessively high fluid temperatures in this instance caused by some abnormal condition in the motors such as high slip resulting from low battery voltage.

In summary, damage of certain insulating materials by hydrolysis is a potential problem not experienced to any known extent in deep submergence practice to date but about which there is very little usable guideline information. In the insulating materials application guides, Chapter V, materials believed to be susceptible to hydrolytic degradation are so indicated.

1.5.3.4 Carbon Contamination

1.5.3.4.1 Sources and Rates of Carbon Generation. Direct-current motors and mechanical circuit interrupters such as on-off contactors cause carbon contamination of the fluid. Brush wear in d-c motors is one source; arcing is the second and generally more significant source. It was noted in paragraph 1.5.1 that pressure-compensating fluids at present are either petroleum-base or silicone liquids. Arcing in both types of fluid produces carbon in addition to other products. Mechanical circuit interrupters opening under load in these fluids can produce substantial amounts of carbon by arcing, and it is possible to predict approximately the rate of carbon generation. It depends on the particular fluid in which the device is operating, the magnitude of the current being interrupted, the circuit voltage, and the number of contact breaks opening simultaneously in the circuit. Table I-3 gives carbon generation rates for three pressure-compensating fluids under one particular set of circuit-interrupting conditions. Arcing of d-c motors due to poor commutation inevitably occurs with prolonged usage but tends to be unpredictable. It is therefore difficult to obtain usable carbon generation data for d-c motors comparable to that for mechanical circuit interrupters. In comparing motors and circuit interrupters as a source of carbon, both the efficiency of commutation of the motor and the factor of continuous or intermittent operation of the motor versus intermittent use of the contactor

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*From unpublished proprietary data.

must be considered. An example may help to put this into better
perspective. On the sister DSV's, SEACLIFF and TURTLE, all
propulsion motors and mechanical circuit-interrupting devices
operate in a single fluid (1 cSt silicone). The side-pod motors
are controlled by circuitry containing contactors which open and
close frequently in normal operation, and under these conditions
the contactors are observed to be consistently much more produc-
tive of carbon than the motors. In the case of a motor that
runs for long periods of time and is turned off and on infre-
quently the motor may generate much more carbon than the switch-
ing devices, especially when commutation is poor.

TABLE I-3
QUANTITIES OF CARBON GENERATED IN THREE
FLUIDS BY 2500 CONSECUTIVE ARCS
(Produced by Interrupting 100 Amperes
D-C at a Circuit Voltage of 120 Volts
with a Single Contact Break at
Atmospheric Pressure)

Fluid	Wt of Carbon, Grams
MIL-H-5605B	0.81
Code C*	0.62
Code E*	1.75
*See Technical Reference 3.	

1.5.3.4.2 Effects of Carbon on Fluid Dielectric Properties. A
large percentage of the carbon that goes into the fluid inside a
pressure-compensated enclosure is of a very fine particle size
(<1 μm) and is slow to settle out. The observed effects of
suspended carbon on two important dielectric properties of two
DOT fluids are shown in table I-1. From these data it appears
that dielectric breakdown voltage of these fluids approaches that
of air (about 4-kv maximum for a 0.05-inch gap) at a carbon
concentration between 0.01 and 0.1 gram per 100 cm^3. This means
that at higher carbon concentrations, dielectric breakdown can
take place more readily at weak spots (such as between adjacent
turns on windings) in insulations immersed in the contaminated
fluid than in air. This is avoided by monitoring as described
in 1.5.3.4.3. Table I-1 shows that a much higher concentration
of carbon is required in these two fluids to reduce resistivity
appreciably than is required to reduce dielectric breakdown
voltage. Similar results have been obtained with at least two
other compensating fluids, Codes C and F fluids.[3] The practi-
cal significance of resistivity of the fluid is that if it drops

too low objectionably high leakage currents may develop in electrical equipment, such as motors, in the pressure-compensated system. Considering the magnitude of resistivity of compensating fluids in general, leakage currents are not likely to be appreciable unless excessive quantities of carbon (or emulsified seawater) are allowed to build up. This also is avoided by monitoring as described in the following paragraph.

1.5.3.4.3 Effects of Carbon on Insulation. Carbon generation rates tend to be relatively high inside distribution boxes housing electrical switching devices of the mechanical type. When this is the case carbon slowly settles out on components and wiring and may adhere to nonhorizontal as well as horizontal surfaces, apparently by electrostatic attraction. The steadily building carbon film causes a gradual decrease in resistance along paths that are required to have a high insulation resistance for satisfactory operation. This problem is dealt with by monitoring resistances to ground from various points within the electrical system. The ground detection system of a vehicle, which is intended for the detection of any potentially dangerous or undesirable ground paths, serves as a convenient means of monitoring high-resistance grounds caused by carbon deposition on insulation. Whenever resistance to ground from any particular point within the electrical system reaches a predetermined lower limit, the fluid is drained and either filtered or replaced with fresh fluid and components are wiped as clean of carbon as practicable. Although the resistance measurements relate primarily to the deposited carbon film, the overall procedure has the effect also of limiting the concentration of carbon (and emulsified seawater) that builds up in the compensating fluid. The principles of ground detection systems as used on Navy ships in general are described in a NAVSHIPS Manual,[7] paragraphs 9600.96 through 9600.98.

Even with such preventive maintenance there is a danger of carbon depositing in critical areas that may be difficult to reach or may be overlooked, such as between turns of windings not filled in by varnish or encapsulant, or in recesses containing terminals at different electrical potentials. Too heavy a build-up of carbon in these areas may promote dielectric breakdown or lead to failure by bridging between conductors at different potentials. Figure I-2 shows an example of insulation destruction due to the latter cause. The voltage and current at which this device operates on the vehicle are low enough that the recessed areas and the proximity of contacts have not created a problem in normal service. The failure came about when the contactor was laboratory-evaluated for possible use at a higher voltage and current than its present service operating conditions.
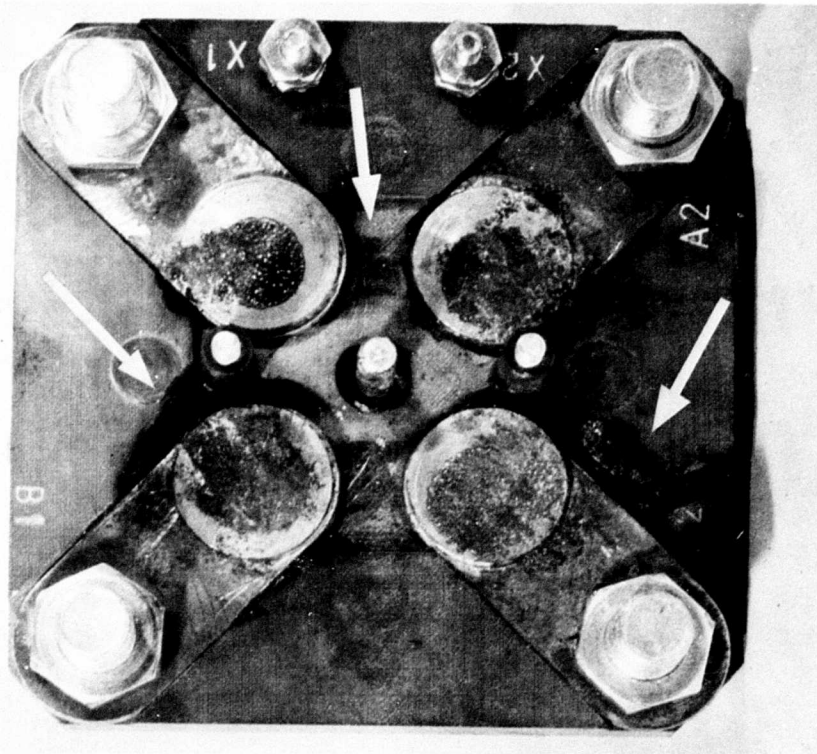
Figure I-2
Contactor of a Type Used on the DSV DEEP VIEW
Armature Has Been Removed Showing the
Stationary Contacts
(Arrows Indicate Burned Out Areas of Laminate
Caused by Carbon Bridging. Carbon and
Decomposition Products Have Been Removed)

In d-c motors carbon deposits may form in windings and/or armature slots and could eventually lead to failure.

Chapters II and III contain further discussions of these problems and how to avoid them or reduce their severity.

CHAPTER II
TYPES OF INSULATING MATERIALS AND THEIR USE
IN PRESSURE-COMPENSATED SYSTEMS

2.1 INTRODUCTION

In this chapter attention will be given to specific categories of insulations, their individual functions, and their use in terms of the considerations outlined in Chapter I.

2.2 USE OF INSULATIONS IN PRESSURE-COMPENSATED SYSTEMS TO DATE

The use of insulations in petroleum-base or other organic liquids is not without precedent. The pressure-compensating fluid environment may be compared to that of oil-filled transformers and capacitors but with the added complications of high pressure, possible seawater leakage, carbon generation, and a greater complexity of materials used. An important fact to be noted in this area of deep-ocean technology is that insulating materials at present are largely off-the-shelf products. They are materials designed primarily for air environments in which they are rated to withstand temperatures as high as 260° C. A large percentage of the insulations presently found on equipment operating in pressure-compensating fluids were not specifically selected for use in fluids. They are there because they happened to be the standard insulations on various off-the-shelf electrical components, such as circuit breakers, which were designed originally for use in air but were installed in deep-submergence applications. When there has been more of a choice, as on propulsion motors designed and built specifically for use in pressure-compensating fluids, there have been very few available guidelines as to what insulating materials are suitable. As a result, insulations on existing vehicles have sometimes suffered deterioration, to varying degrees, in contact with fluids. The problem of finding acceptable materials is basically a matter of determining which of the numerous insulations already on the market are satisfactory.

2.3 SPECIFIC TYPES OF INSULATIONS USED

The major electrical items requiring insulation on a deep-submergence vehicle or system are the following:

(1) Motors, both d-c and a-c, for propulsion and other functions.

(2) Mechanical circuit interrupting devices, i.e., relays, contactors, and circuit breakers.

(3) Transformers and inductors.

(4) Lead wire for interconnecting various components.

(5) Fuses.

(6) Batteries.

(7) Cables.

Conventional insulating materials used in fuses and those used in batteries, for normal air environments, have been found by past experience not to be a problem in compensating fluids. Compatibilities between fluids and cable materials are treated separately in the DOT cables handbook,[8] pages III-16 to III-18. The insulations which are dealt with in this handbook are, therefore, primarily those used on items (1) through (4) above: magnet wire film, sheet insulation, lead wire, sleeving, varnish, laminates, and molding compounds. Materials in these categories, except for laminates, were selected from products available on the market and evaluated in a program at this Center which yielded the data in Chapter V. The nature and function of each of these types of insulations are discussed in the following paragraphs with reference to their use in compensating fluids and are summarized in table II-1.

2.3.1 Magnet Wire Film Insulation

This is a thin polymeric material which can be either a single coat system, which means it is a single polymer material, or an overcoated system in which there are two different materials making up the film. The purpose of the magnet wire film insulation is to provide separation of the copper conductors sufficient to withstand the voltage stresses normally encountered in a wound component. The polymeric coating provides turn-to-turn insulation. In a motor this insulation would be within a stator or rotor slot from turn-to-turn, and the voltage depends upon the design and operating voltage of the motor. In a 440-volt a-c induction motor, for instance, the turn-to-turn voltage is generally in the vicinity of 25 volts or higher; while in a d-c motor for deep-submergence use, which may have an operating voltage as low as 60 volts, the turn-to-turn voltage may be as low as 3 to 4 volts. In inductors and solenoids there is also a potential between the conductors although it may not be as great as

that in a motor. However, if the coil is designed in such a manner that layer-to-layer insulation is not used there may be full-line potential across the polymeric coating. The stresses other than electrical that the magnet wire sees during its lifetime include mechanical stresses from vibration due to the current in the coil such as in a motor. Vibrational stresses exist in both a-c and d-c motors. There are also stresses on motor windings as a result of starting. This is primarily in the end turn area of the motor and consists of a repulsion of the coils from one another. Another type of stress is abrasion which can occur in the winding operation. These stresses tend to damage the magnet wire film and may even cause it to peel or flake off the conductor wire. Abrasion prior to immersion of the wound component in a compensating fluid makes the polymer coating more vulnerable to any possible effects of the fluid. Conversely, any attack by the fluid which may, for example, result in softening or embrittlement of the film causes it to be more readily damaged by vibrational stresses after immersion in the fluid. This may then result in turn-to-turn short circuiting which could involve some arcing and carbon bridging, described in Chapter I (1.5.3.4.3). The carbon bridge makes a short circuit of moderate resistance, frequently producing heat in high concentration, which may cause further destruction of insulation and lead to a complete breakdown of the wound component. Three major points of vulnerability of magnet wire film materials in fluids are:

- Their relative thinness (see table II-1).

- The problem of adhesion of organic films to metal surfaces.

- The proximity of individual turns to one another tending to cause abrasion under the vibrational stresses previously described.

Hydrolytic degradation was noted in Chapter I (1.5.3.3) to be a potential problem with magnet wire film materials in particular. This is partly because of the leakage of outside ocean water through motor shaft seals, because of heat generated by the motors and also because of the threefold vulnerability of magnet wire films just mentioned. The application of varnish, discussed in Section 2.3.4, reduces the severity of these various problems considerably. For air applications, varnish is usually applied to motor windings but not always to the solenoid windings of contactors and circuit breakers. For a pressure-compensating

fluid environment, varnishing appears advisable for most wound components because of the problems just discussed. It also is advisable because of the tendency of carbon generated by arcing to settle between turns on an unvarnished wound component and further compound these problems. Some off-the-shelf mechanical circuit-interrupting devices have encapsulated coils. This has in general been found to provide quite satisfactory protection in fluids although the encapsulant adds to the weight.

TABLE II-1
TYPES OF INSULATIONS USED IN DEEP-
SUBMERGENCE APPLICATIONS

Insulation Type	Nature of the Insulation	Function	Thickness Range
Magnet wire film	Thin polymeric coating applied at the mill.	Turn-to-turn insulation in wound components.	0.1 to 5 mils
Sheet material	Thin sheet, variable; polymeric and inorganic materials such as glass fiber and mica. May be single sheet or sandwich construction.	As phase and ground insulation in motors; separation of terminals and other conducting surfaces in circuit interrupting devices.	1 to 60 mils
Lead wire insulation	Polymer material having elastomeric properties.	To insulate copper lead wire.	2 to 20 mils
Sleeving	Woven glass fabric impregnated with polymeric material.	To cover joints such as magnet wire connected to lead wire or for additional protection over lead wire.	30 to 75 mils
Varnish	Polymeric material, usually dissolved in a solvent and applied by dipping. 100% solids varnishes are a new development.	Applied over wound components to bond magnet wire and give it additional environmental and dielectric protection.	Variable; less than 0.5 mil in thinnest spots, up to 1/8 inch in heaviest areas.
Laminates	Glass cloth impregnated with polymeric material.	Structural strength and insulation.	0.01 to 3.5 inches.
Molding compounds	Polymeric materials that can be molded to desired shapes.	For cases and structural parts of circuit breakers, contactors, and other circuit-interrupting devices.	Variable; 1/16-inch to several inches

2.3.2 Sheet Insulation

Sheet material is used predominantly as ground or phase insulation in motors and comes in many forms. It may be a single polymeric material in paper form, such as polyamide paper, or a sandwich construction as a glass-mica-glass sheet. It provides

separation of magnet wire from the ground or laminated steel structure, so the sheet insulation will normally be subjected to a higher electrical potential than the polymeric material used on magnet wire. The ground potentials are those of the core of a motor or of a transformer. Sheet material is also subjected to mechanical stresses. In an electric motor there are high laminations that apply stresses to the ground material at pressure poi ts, and as a result the thickness of the material (see tab. II-1) must be much greater than would normally be expected r its breakdown strength. In addition, material is subjected to forces from being bent around sharp corners as in a transformer lamination or in the edge of slots of motors. It is also subjected to vibrational forces from the magnet wire.

The major problem with sheet insulation for use in pressure-compensating fluids, as with magnet wire enamels and varnishes, is compatibility with the fluid. In the case of sandwich constructions, the bonding material holding the individual layers together may be susceptible to softening and disintegration by the fluid with resultant delamination. Embrittlement may also be a problem in that under some conditions the sheet material may break or crack in service. Hydrolytic stability is of concern with materials of chemical types that are subject to hydrolysis when seawater leaks into the pressure-compensated system. (In reference to the two latter points see data tables V-9 through V-15 in Chapter V.) The manner in which phase and ground insulation is inserted in motor windings results in pockets in which carbon can be trapped and be deposited between the windings. This can be minimized by developing the maximum possible build of subsequently applied varnish. Note limitations of conventional solvent varnishes as stated in Section 2.3.4. In components such as contactors and circuit-breakers, sheet insulation may be used to form barriers between conductive surfaces which are at different potentials (terminals, for example) to prevent bridging over of carbon. In such instances, every effort should be made to prevent or minimize the possibility of carbon entrapment.

2.3.3 Lead Wire Insulation and Sleeving

Lead wire is usually made up of stranded copper conductors covered with a polymeric material having some elasticity (similar to rubber) which allows flexibility. It is used to join the external circuit to the components and experiences voltage stresses which are at full-line potential. Stresses other than electrical on the lead wire are those from being bent around sharp corners and repeated flexing from connecting and disconnecting circuits. Sleeving is normally a woven glass fabric

impregnated with a polymeric material for strength as well as additional dielectric protection. It is used over joints and may be subjected to forces due to high copper and uneven joints. It is also subjected to high potentials in that full-line potential may occur across the sleeving. It is used in some places to cover the joint between lead wire and magnet wire. In addition, sleeving may be used over lead wires of transformers or inductors where they are brought out to terminal boards. Compatibility with fluids, and to a lesser degree hydrolytic stability, are the major problems with lead wire insulation and sleeving used in pressure-compensated systems. Lead wire insulation may soften, swell, elongate, or become embrittled. The latter may result in breaking or cracking, especially when the wire has been bent around sharp corners. Sleeving presents somewhat less of a problem than other insulation, because if the polymeric material softens in the fluid, the glass fabric may continue to maintain the integrity of the insulation provided the effect of the fluid is not too severe. However, embrittlement may result in cracking or breaking of the insulation, as with lead wire. Shrinking may also result in some loss of function.

2.3.4 Varnishes, Solvent, and 100% Solids

These are polymeric materials usually dissolved in a solvent and applied over wound components after the components are fully assembled. The varnish covers primarily the magnet wire film insulation but may also cover sheet material such as phase and ground insulation on motors and a portion of the lead wire and sleeving. The manner of application is as follows: the component is dipped into the varnish, removed, and subjected to a baking procedure to cure the varnish. Baking schedules vary with individual proprietary varnish products. Baking drives off the solvent and cures the remaining polymer coating. The main functions of a varnish, as used in an air environment, are environmental protection of the wound component and bonding, i.e., holding of the magnet wire in place to prevent or reduce the vibrational stresses described in Section 2.3.1. The first of these functions is somewhat different in compensating fluids than in air. The varnish represents an additional barrier against penetration by the fluid and probably provides some extra protection against possible hydrolytic attack. The second function, bonding, is just as, or perhaps more, important in fluids than in air for the reasons stated in Section 2.3.1. Another beneficial effect of the use of varnish in compensating fluids is the filling in of spaces between windings which prevents a possibly harmful deposit of carbon from forming in those areas. At the

same time it fills pinholes and abrasions that may have been present in the magnet wire film insulation originally or may have been produced during the winding operation. For these functions to be performed successfully, it is essential to have an adequate build-up of varnish. Conventional varnishes are far from ideal in this respect, but the 100% solids (solventless) varnish may be found more effective in the future. See Section 2.3.4 and Chapter V for further discussion. The possible harmful effects of compensating fluids on varnishes are softening, partial dissolving, and embrittlement. Any of these effects may destroy completely the proper functioning of the varnish. Unfortunately, varnish that separates from the magnet wire for any of these reasons may carry the magnet wire film with it. Thus, the effectiveness of a given varnish depends on both magnet wire film and varnish being compatible with the pressure-compensating fluid. A varnish that has poor compatibility (tends to deteriorate in the fluid) when applied over a "good" magnet wire insulation may produce a poor system overall. This can be seen from the data in Chapter V, table V-7, comparing Code E magnet wire film alone to Code E magnet wire film coated with Code K varnish. Conversely, a "good" varnish applied over a poor to mediocre magnet wire film may yield a poor to mediocre system overall, as seen in table V-3, comparing Code A magnet wire film alone to Code A magnet wire film coated with Code F varnish.

It was indicated in the previous paragraph that conventional solvent varnishes do not provide an adequate film buildup to completely fill in spaces between windings, etc. The reason for this is primarily shrinkage in volume due to solvent loss on curing. A new type of material in insulation technology, the so-called 100% solids varnishes, is considerably superior in this respect, and it is expected that experience will show it to perform much more satisfactorily in deep-submergence applications than conventional varnishes. The new materials are supplied as liquid resin mixes containing no solvent. At least three resin types are available: polyester, epoxy, and butadiene. The varnish is applied by vacuum-pressure impregnation or by simple dipping. During curing (baking), there is generally less than 5% material loss (by evaporation); i.e., most of the liquid resin polymerizes to form the varnish film. As a result, films of the 100% solids materials are several times the thickness of conventional varnish coatings. Furthermore, some of the 100% solids formulations contain thixotropic agents. These are compounds that modify the liquid varnish properties in such a way that, while the varnish can be poured and stirred readily, it leaves a relatively thick film on draining. This makes it possible to increase the varnish coating thickness severalfold more. Unfortunately, the 100% solids varnish formulations did not

enter prominently into the insulation field until after the DOT insulating materials evaluations were well underway at this Center. Therefore, no data were obtained on compatibility with pressure-compensating fluids for any of these new varnishes. Chapter V (5.4.2) contains one datum point for hydrolytic stability of a polyester-type 100% solids varnish film over a polyimide magnet wire film. There is also a discussion in Section 5.4.2 of field experience with several 100% solids varnishes over a-c motor stators in a pressure-compensated system.

Since the 100% solids varnishes have the attractive feature just described, potential users must be cautioned against placing any of these materials in pressure-compensated systems before data on compatibility with fluids are available. Such data, if not available in a later edition of this handbook or from other sources, can be determined for a given material by the procedures of Chapter IV. See especially Sections 4.1 through 4.9.1 and 4.10.2. High-pressure testing can probably be dispensed with.

2.3.5 Laminates

These are glass cloth impregnated with thermosetting polymeric materials. Their purpose is to provide structural strength in addition to insulation. The voltage stresses may be similar to that found on a contactor in which there is full-line potential from terminal posts. As with other insulations, the major problem in pressure-compensating fluid applications is compatibility with the fluid. Hydrolytic stability is of less concern. Laminates were not laboratory evaluated in the program from which the data of Chapter V were derived. However, they seem to be among the least critical materials for use in fluids. Possible harmful effects of fluids are delamination and loss of structural strength. A discussion of laminates based on in-service experience will be found in Chapter V (5.9).

2.3.6 Molding Compounds

These are thermosetting polymeric materials that can be molded to desired shapes. The polymeric material may contain admixtures of asbestos, glass fiber, or cellulose fiber fillers. They are used primarily for making cases and structural parts of circuit breakers, contactors, and other circuit-interrupting devices. These materials, when immersed in pressure-compensating fluids, may undergo weakening that results in cracking or breaking.

CHAPTER III
ELECTRICAL INSULATION IN THE DESIGN
AND USE OF SPECIFIC DEVICES

3.1 INTRODUCTION

Wound components such as electric motors, transformers, and
inductors and circuit interrupting devices such as circuit
breakers, contactors, and relays use all seven types of insulating
materials previously discussed: magnet wire film, sheet material,
lead wire, sleeving, varnish, laminates, and molding compounds.
Consideration must be given to making the most effective use of
these materials in the fluid environments in which they are to
function. In this chapter several aspects of this problem will
be considered.

3.2 COMPATIBILITY OF INSULATIONS IN COMBINATION WITH ONE
ANOTHER AND WITH FLUIDS

The types of degradation to which insulating materials in
compensating fluids are subject have been described in the pre-
ceding chapter (Sections 2.3.1 through 2.3.6). The nature of the
deterioration is undoubtedly complex and is not completely under-
stood. In air environments, insulation undergoes simple thermal
decomposition but can also deteriorate through chemical reactions
with environmental constituents such as oxygen and moisture.
In a compensating fluid environment it seems likely that gradual
degradation of insulating materials, when it occurs, is due
primarily to a combination of thermal decomposition and reaction
with the fluid, the latter being accelerated by increasing
temperatures at the fluid-insulation interface. With some insula-
tion there may be hydrolytic attack when water is present at
temperatures of 100° C or higher. Rapid thermal decomposition,
including carbonization, may take place at extreme temperatures
that arise from severe electrical faults. The question of
possible interaction between individual insulations in the fluid
medium must also be considered. In Chapter II (2.3.4) an apparent
reaction between magnet wire film insulations and varnish was
described. When a poor (with respect to fluid compatibility)
varnish is applied over a magnet wire film which by itself is
unaffected by the fluid, the overall system may be poor; i.e.,
it may deteriorate readily in the fluid. (Conversely, when a
"good" varnish is applied over a poor magnet wire film, the
resultant overall system may be poor.) Although data on
varnishes in combination with other insulations are lacking at
present, there may be a similar tendency when varnishes cover
lead wire and sleeving. Therefore, it is important to choose

all of these insulations carefully, since a poor varnish may have
a deleterious effect on magnet wire films or other insulations
which are otherwise compatible with the fluid. The question
also arises as to whether a fluid contaminated with decomposition
products of one insulation will have more of a tendency to react
detrimentally with other insulations than the uncontaminated
fluid has. The evaluation program at this Center did not answer
this question. However, if none of the insulations individually
are subject to significant attack and degradation in the fluid
there is little likelihood of such a contaminating effect taking
place. In summary, all insulating materials in a given pressure-
compensated enclosure should be chosen as carefully as possible
with respect to fluid compatibility. If all of the insulations
in a system are individually satisfactory in this respect there
should be no problem with the insulation system as a whole in the
fluid environment.

3.3 SELECTION OF MAGNET WIRE

There are two options in choosing magnet wire for windings.
One is to use a small number of turns, high current, and a large
wire; the other is to use a small wire, large number of turns,
and small current to achieve the same number of ampere turns.
With the present state of the art there is a problem if one uses
a small wire with many turns, for there is no varnish that has to
date been demonstrated to give a completely suitable bond over
a long period of time in compensating fluids. Although table
V-2 in Chapter V recommends one varnish that is indicated to be
acceptable in both petroleum-base and silicone fluids, it must
be considered borderline. If there is any tendency toward
either embrittlement or softening of the varnish in the fluid,
the small wire tends to fail as a result of vibration of the con-
ductors under the effect of the magnetic field. Larger wire has
sufficient rigidity that vibration does not present these dif-
ficulties. Under the present state of the art this argues for
the use of a larger wire with higher current to achieve a given
number of ampere turns. This consideration, however, may have
to be balanced against the desirability of keeping current as low
as possible to minimize I^2R heat. See further discussion in
Section 3.5.

3.4 INSULATION IN RELATION TO MECHANICAL DESIGN

The harmful effects of carbon depositing in recessed areas
of components and the danger of bridging across terminals, etc.,
were discussed in Chapter I (1.5.3.4.3). Figure III-1 illustrates
how possible problems of this type were avoided on a relay that
was modified for deep submergence use. The terminals facing

III-2

front (the coil connections) before modification are close enough together that carbon bridging could take place. Replacing the metal cover with an insulating laminate accomplishes three things:

- It reduces the possibility of a high-resistance short-circuit between the main contact terminals (threaded lugs, on left- and right-hand sides of the relay body) by carbon deposition on the external surfaces.

- It permits relocating the coil terminals and increasing the distance between them by three- to fourfold.

- By leaving an open space it allows carbon generated at the contacts to fall free (the contactor is mounted with the laminate in a vertical plane) rather than be trapped inside the relay body.

1.   Closely Spaced Coil Connections
2.   Modified Coil Connections with Wider Spacing
3.   Insulating Laminate

Item (a) - Closely Spaced Coil Connections   Item (b) - Modified Coil Connections with Wider Spacing

Off-the-shelf automotive relay (contactor) as purchased   Modified for use on the DSV ALVIN in pressure-compensating fluid
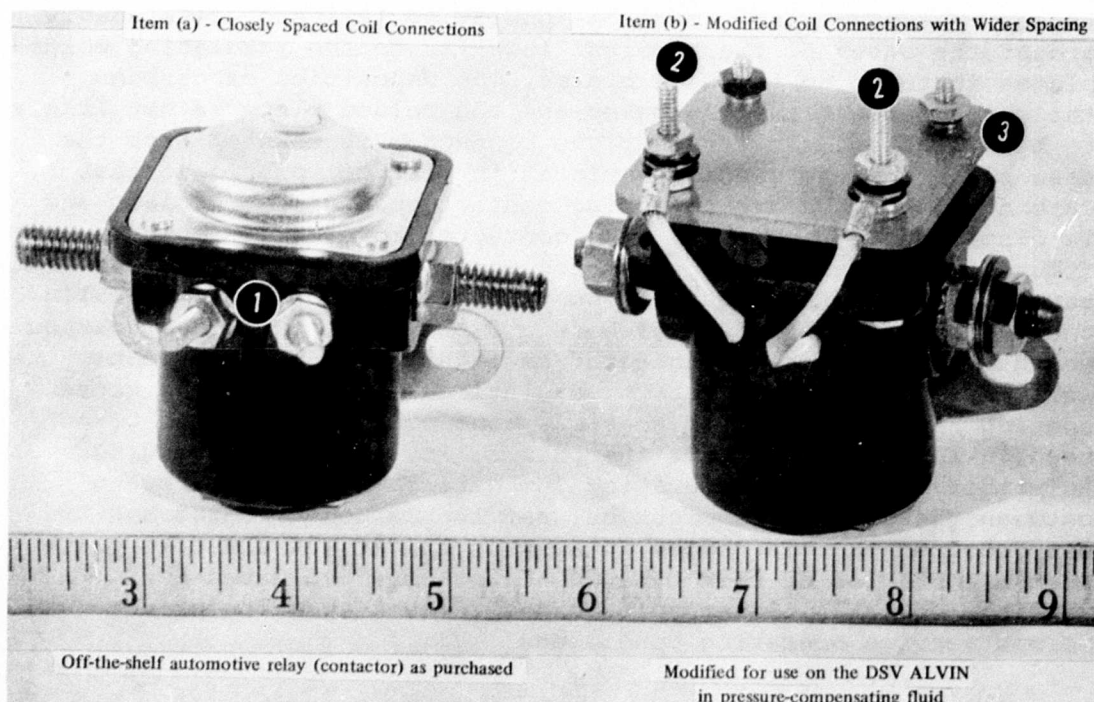
Figure III-1
Modification of Contactor to Reduce Problems
of Carbon Deposition

With regard to carbon deposition on external surfaces it was noted in Chapter 1 (1.5.3.4.3) that thin layers of carbon may be deposited on surfaces in other than a horizontal plane apparently by electrostatic attraction. In general, it is important to separate conducting surfaces at different potentials and extend creepage paths as much as practical by a judicious use of insulating materials, as in air environments. In distribution boxes housing mechanical contactors, where arcing and carbon generation rates are appreciable, insulation problems may be more severe than in air environments because of carbon depositing on components and wiring. In addition to the points noted above, positioning of components when they are installed on the submersible is important to allow carbon to fall free. Insulating materials such as sheeting and laminate should be placed in such a position that they do not act as traps to catch and allow a buildup of carbon that might bridge across terminals, etc. The device of figure III-2 is an illustration of these various principles. Under each strip of laminate are two sets of contacts, one set of which can be seen at lower center in figure III-2. The spacing between contacts and the metallic terminal lug bases (upright pieces to which the stationary contacts are attached) is relatively large. The base plate, made of insulating laminate, fits snugly around the bases of the terminal lugs, as do the insulating molded plates fastened to the base plate. The deposition of carbon in the space between the lug bases and the molded plate is not likely to be a problem. In service, the contactor is mounted with the base plate and the contact surfaces in vertical planes so that carbon produced by arcing during contact opening falls clear and is dispersed in the fluid. The contactor cover (not shown in figure III-2) has openings through which fluid can freely circulate, thus minimizing the accumulation of carbon inside. In general, there are no recessed areas where a detrimental buildup of carbon would take place. The contactor of figure III-3 is reasonably well designed with respect to insulation, except that the close spacing between the fixed contacts (one pair of which can be seen in the figure) allows the possibility of carbon bridging. A further buildup of insulating laminate to fill in the space between these contacts might be useful. Carbon bridging has not occurred on this device in service so far but did take place when a contactor of this type was laboratory evaluated for possible use at a higher voltage and current than its present normal service operating conditions.

1. Insulating Laminate   2. Contacts
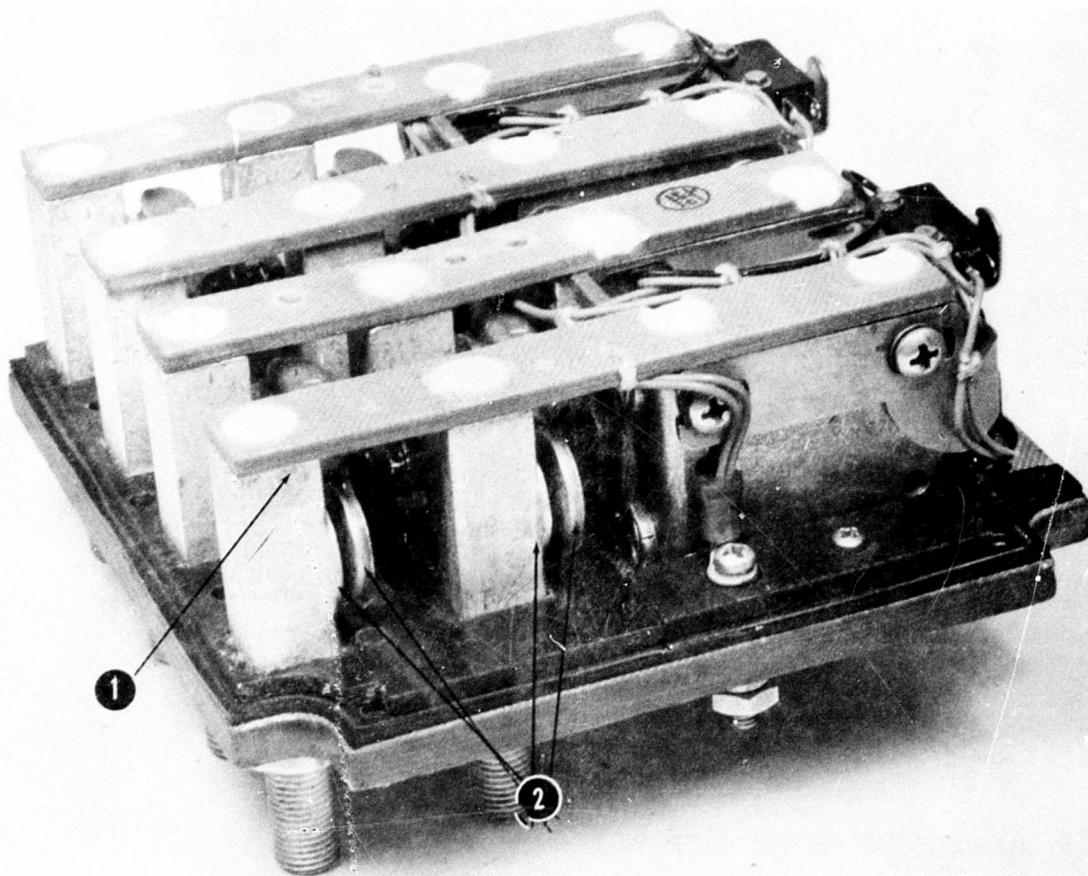
Figure III-2
Motor Controller Contactor of the Type Used
on DSV's TURTLE and SEACLIFF, with
Cover Removed

1. Contacts
2. Close Spacing of Stationary Contacts
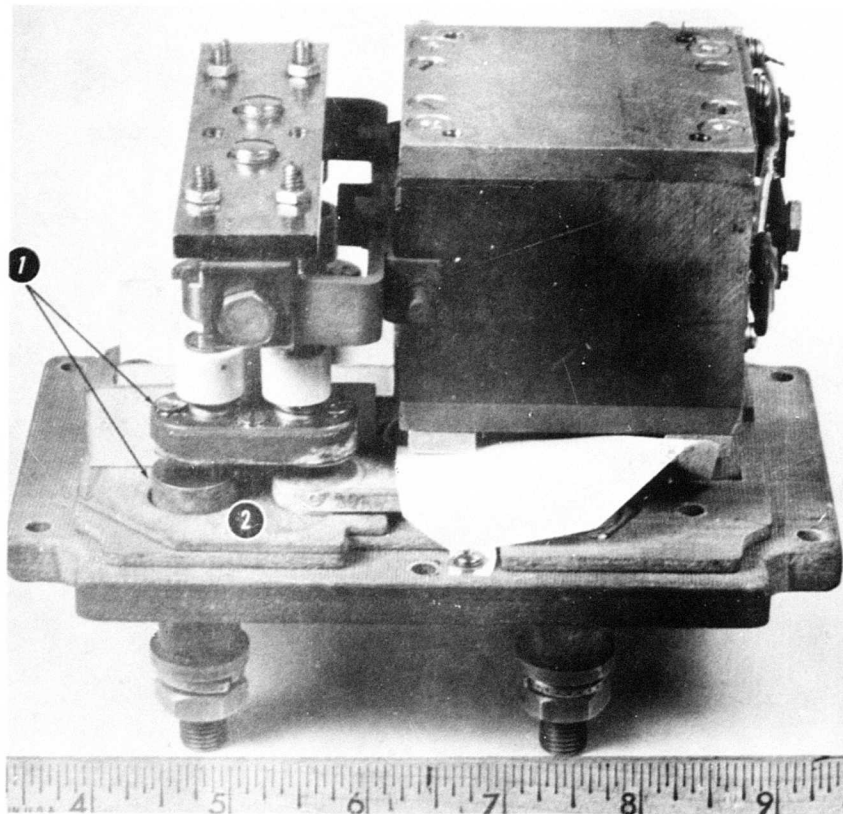
Figure III-3
Circuit-Breaker Contactor of the Type Used
on DSV's TURTLE and SEACLIFF with
Cover Removed

3.5 MINIMIZING TEMPERATURE RISE

Heat is produced from several sources within pressure com-
pensated enclosures housing electrical equipment: from wound
components and conductors as I^2R losses, from arcing, and from
fluid friction especially in motors. The temperature differential
between the inside of the enclosure and the external ocean is the
resultant of the rate of heat generation internally, less the
rate of heat transfer to the ocean. Since any tendency toward
interaction between compensating fluid and insulating materials
is greater, the higher the temperature of the fluid, it is

desirable to keep this temperature differential as low as possible. This will obviously be accomplished by any means that reduces the rate of heat generation or increases the rate of heat transfer to the outside.

3.5.1 Temperature Rise Versus Fluid Viscosity

An approach that both decreases heat generation and increases heat transfer is to use the lowest viscosity compensating fluid consistent with other requirements (such as lubrication). Heat transfer through the liquid and across liquid solid interfaces to the external ocean increases with decreasing fluid viscosity, while heat generated by fluid friction in motors decreases with decreasing viscosity.

3.5.2 Reducing Frictional Heat in Motor Design

It is also possible to minimize fluid friction in a motor by the design of the motor itself, as illustrated in figure III-4. The end turns of the rotor, item (a), figure III-4, and the wire leading from the rotor iron to the commutator produce an appreciable amount of fluid friction when the rotor is turning. On the rotor of item (b), figure III-4, fluid friction has been reduced by enclosing the end turns and by covering the wire between the rotor iron and the commutator with a polytetrafluorethylene insulating sleeve. Note also on the rotor of item (b), figure III-4, that the recesses in the rotor slots, between the surface of the rotor iron and the tops of the slot wedges, are not as deep as on the rotor of item (a), figure III-4.

3.5.3 I^2R Heating in Magnet Wire

In Section 3.3 the selection of magnet wire for wound components was considered on the basis of minimizing the effects of vibration due to current flow. The conclusion was that for a given number of ampere turns, a relatively large wire carrying a relatively high current is preferred over a smaller wire carrying a lower current to avoid the destructive effects of vibration. However, I^2R heating should also be considered. In the simplest case, that of a d-c circuit in which the wound component, say the coil of a circuit breaker, contributes most of the circuit resistance, the rate of heat generation, I^2R, can also be expressed as E^2/R where E is the circuit voltage. The higher the current through the coil, the lower its resistance, R, must be. This corresponds to a large wire having a small number of turns, and consequently, the greater the generated heat E^2/R ($=I^2R$), will be. Thus, the size of the magnet wire may logically be a compromise between a size large enough to avoid the undesirable

effects of vibration and one small enough to keep the I^2R heat to a desired minimum. Similar reasoning can be applied to more complicated d-c and a-c circuits to estimate the relative importance of I^2R heat of wound components in a given circuit as an aid in selecting the size of the magnet wire.

Item (a) - Used on 20,000-Foot Work Systems Package

Item (b) - Built as a Backup Unit for Possible
Use on 20,000-Foot Work Systems Package
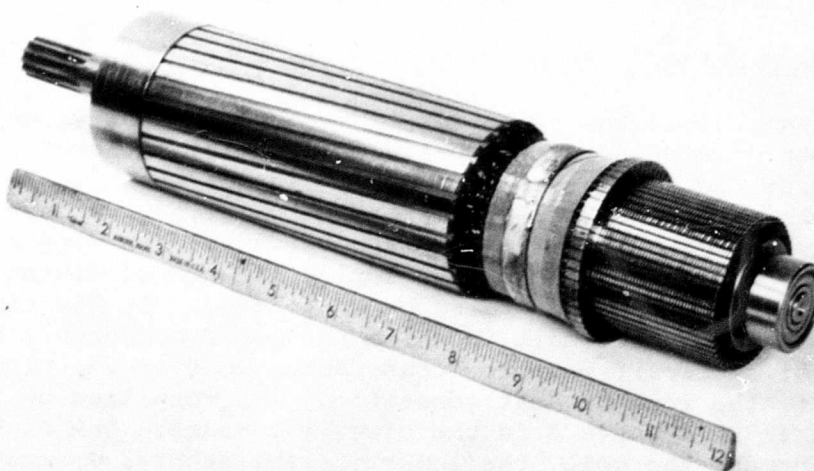
Figure III-4
Comparison of Rotor Designs of Two 6-HP D-C Motors,
with Respect to Fluid Frictional Losses

3.5.4 Temperature Rise Due to Arcing of Mechanical Circuit Interrupters

Mechanical contactors which open and close frequently under load may generate an appreciable amount of heat along with carbon. Both heating and carbon generation can be reduced by decreasing the amount of arcing. This can be done in several ways but primarily by the use of multiple contact breaks in series. Mechanical circuit breakers, while they may contribute a considerable amount of I^2R heat, produce very little heat by arcing since they open only under fault conditions. For a detailed discussion of arcing in fluids see the DOT circuit interrupting devices handbook,[9] Chapter I.

3.5.5 Heat Production Due to Poor Commutation in D-C Motors

D-C motors should be designed as optimally as possible for efficient commutation. From the standpoint of insulation problems, the absence of arcing eliminates a source of heat and means less carbon accumulating in the motor enclosures. For a comprehensive treatment of d-c motor design and commutation, see the DOT drives handbook.[1]

3.6 MONITORING OF INSULATIONS IN SERVICE

Ground detection systems (see also Chapter I, 1.5.3.4.3) on deep-submergence vehicles detect insulation deterioration and high-resistance (e.g., less than 100,000-ohm) short circuits to ground caused by the deposition of carbon on insulation surfaces. These deposits must be cleaned off periodically to restore insulation resistance to more normal values (e.g., of the order of several megohms). A periodic visual inspection of insulations should also be made. To be fully effective, this may require partial disassembly of some components. Extreme failure or near-failure conditions may be obvious on visual inspection. This includes such conditions as cracking, splitting, flaking and peeling of magnet wire and varnish, extreme swelling, softening, disintegration, and partial dissolving or charring due to severe heat. Insulations should also be examined for less extreme conditions which may represent not actual failures but warnings of possible future difficulties. These include slight softening, tackiness, hardening, and embrittlement. Discoloration of insulating materials may indicate a reaction with the fluid although this may be quite minor and should not in itself be considered a sign of failure or impending failure. It may suggest that the material should be examined more closely. A close inspection should be made for carbon in recessed areas such as in

spacings between windings that have not been filled or covered with varnish. Insulations should also be examined for signs of destruction by arcing, especially where there are thick adherent deposits of carbon which may indicate that arcing has taken place in that location.

CHAPTER IV
EVALUATION METHODS FOR DEEP-SUBMERGENCE
ELECTRICAL INSULATING MATERIALS

4.1 INTRODUCTION

The procedures described in this chapter are those that were used in the DOT insulating materials program at this Center for evaluating a total of 26 materials yielding the data of Chapter V. It is hoped that they may also serve as a guide for future evaluations of this type elsewhere.

4.2 GENERAL PROCEDURE

Insulating materials to be used in pressure-compensating fluids must have satisfactory dielectric quality as manufactured and must retain this quality during prolonged immersion at varying temperatures and pressures. The retention of insulating quality depends to a large degree on the material's retention of physical integrity; i.e., it must not deteriorate in contact with the fluid. Therefore, both the physical integrity and dielectric properties of the materials were examined. The procedure was to immerse an appropriate number of samples of the insulation in three representative pressure-compensating fluids for 240 or 364 days at different pressure-temperature combinations. Measurements and visual observations were made on the samples prior to immersion. After immersion, samples were withdrawn at intervals for repeated measurements and observations. Details of these procedures follow in Sections 4.3 through 4.9.5.

4.3 PRESSURE-COMPENSATING FLUIDS

Three fluids were chosen for the evaluation as representative of a wide range of possible DOT fluids[3] in which electrical insulations might be used:

- One cSt silicone fluid per MIL-S-21568A.

- Hydraulic fluid per MIL-H-6083C.

- Electrical insulating oil per VV-I-530a.

The first of these was selected since it is the most widely used member of a family of silicone pressure-compensating fluids and probably the most severe of the various silicones in its effect on insulation. It was in use in electrical distribution

boxes on the DSV TRIESTE as early as 1967, the DSV's TURTLE and SEACLIFF dating from 1969, and on the DSV DEEP VIEW for a number of years. MIL-H-6083C fluid was chosen because it is a petroleum-base material having a relatively high percentage of additives which are believed to increase the possible interaction with insulations. This product is in use on the DSRV's at this writing as the pressure-compensating fluid for a-c motors. Except for having one more additive it is identical to MIL-H-5606B hydraulic fluid, which has been used successfully for housing circuit interrupters on the NEMO. VV-I-530a electrical insulating oil was selected for the program as representative of petroleum-base fluids containing essentially no additives.

4.4 IMMERSION CONDITIONS

The lowest temperatures in the deepest known parts of the ocean are at least several degrees below 32° F (0° C). At the opposite extreme, many of the insulations evaluated and reported in Chapter V are rated for temperatures as high as 200° C and in several instances as high as 260° C for air environments. A maximum of 90° C was chosen as reasonable for the evaluations in compensating fluids. Testing of insulations in fluids at tempera-ture below normal room ambient was felt to be unnecessary because any reaction between fluid and insulation is merely slowed down as temperature is lowered. The temperatures of 25±5° and 90° C were therefore chosen for the evaluations. With regard to pressure, the greatest known depth of the ocean is about 35,000 feet. For convenience, 13,200 psig, corresponding to a depth of about 29,000 feet, was chosen as the upper pressure limit and atmospheric pressure as the lower limit. It was decided to use the four limiting conditions, i.e., the four combinations of temperature and pressure for the evaluations:

- Atmospheric pressure 0 psig and 25±5° C.

- Atmospheric pressure 0 psig and 90° C.

- 13,200 psig and 25±5° C.

- 13,200 psig and 90° C.

The exposures at high pressure were essentially static pressure tests rather than pressure cycling (between atmospheric and high-pressure) which is sometimes used in simulating pressure changes on deep-submergence vehicles corresponding to submerging and surfacing. However, since samples were withdrawn at five inter-vals there were in effect five pressure cycles over the 240-day exposure period. As a result of this Center's work there is now

some question as to whether evaluation under high pressure is
really necessary. For further discussion of this point see
Section 4.10.2. Twenty-six insulating materials were involved
in the Center's program but because of the magnet-wire enamel
varnish combinations, a total of 33 insulation systems were
studied. Twenty-five of these were immersed under all four and
the remaining eight under the first two of the exposure conditions,
in the three evaluation fluids, for total times of 240 and 364
days, respectively.

4.5 HANDLING OF SAMPLES

Details of sample preparation and testing of the individual
insulations are given in Sections 4.9.1 through 4.9.5. Procedures
common to all materials are described in this and the following
sections through Section 4.8. The samples evaluated at atmospheric
pressure were placed in covered cylindrical steel containers
$3\frac{1}{2}$ inches in diameter and $11\frac{1}{2}$ inches high (figure IV-1). Samples
of only one type of insulation were put in a given container,
with a given fluid, to avoid cross-contamination. The $25\pm5°$ C
containers were stored on shelves in an air-conditioned laboratory,
and the 90° C containers were kept in an oven at $90\pm2°$ C. For
the 13,200 psig evaluations, groups of samples were placed in
polyethylene bags with the appropriate fluids, and the bags were
sealed prior to being put in the pressure vessels to facilitate
later withdrawal at the specified time intervals. The pressure
vessels and auxiliary apparatus are described in Section 4.7.
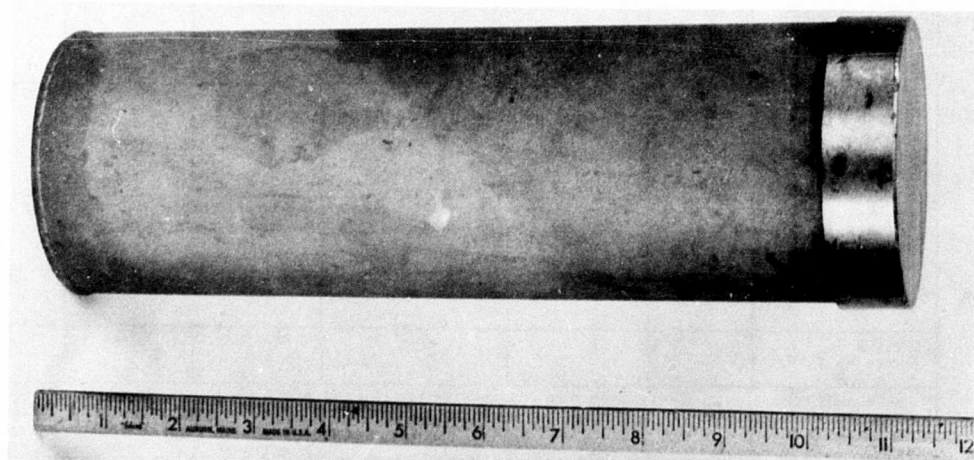
Figure IV-1
Container for Atmospheric Pressure Evaluations

4.6 MEASUREMENT AND INSPECTION SCHEDULE

Codes A and B magnet wires with and without varnishes were evaluated at atmospheric pressure only. Samples of these materials were withdrawn for testing and visual examination at 28, 112, 196, 280, and 364 days. Samples of all other materials, at both atmospheric pressure and 13,200 psig, were withdrawn at 1, 30, 60, 120, and 240 days. Samples of molding compounds were returned to the fluid after each withdrawal and measurement since only dimensions were measured. Three samples of each molding compound were used for each fluid at each exposure conditions, i.e., 3x2x3x4=72 samples total. The tests on all other insulations evaluated, i.e., breakdown voltage and bend test, were destructive, so that it was necessary to prepare a sufficient number of samples to be able to discard those tested at the end of each time interval. The detailed schedule of samples used in the evaluation program is shown in table IV-1.

TABLE IV-1
SAMPLES USED IN DTNSRDC DOT ELECTRICAL
INSULATION STUDY

Insulations Evaluated	a No. of Insulations Evaluated	b No. of Samples of Each Insulation Tested Not Immersed in Fluid	c No. of Samples of Each Insulation Withdrawn from Each Fluid, at Each Exposure Condition, at Each of the 5 Time Intervals[1]	d Total No. of Samples Immersed in 3 Fluids at 0 psig (25 ± 5 and 90° C)	e Total No. of Samples Immersed in 3 Fluids at 13,200 psi (25 ± 5 and 90° C)	f Total No. of Samples Used (Columns "a" times "b" plus Columns "d" and "e")
Magnet Wire Codes A and B film insulations, film alone, and with Codes F, G, and J varnishes	8	10	10	8x10x5x3x2= 2400	0	2480
Codes C, D, and E film insulations, film alone, and with Codes H and K varnishes	9	5	5	9x5x5x3x2= 1350	1350	2745
Sheet Materials Codes L, M, N, O plus OVMG and SVMG	6	3	3	6x3x5x3x2= 540	540	1098
Lead Wire Codes P, Q, and R	3	3	3	3x3x5x3x2= 270	270	549
Sleeving Codes S, T, U, V, and W	5	3	3	5x3x5x3x2= 450	450	915
Molding Compound Codes Y and Z	Note:	Same samples returned to fluids after each withdrawal and measurement, at the designated time intervals.[2]				(Calculation at head of column does not apply)
	2	3	3	2x3x3x2=36	36	72

Total of all samples tested 7859.

[1]See Sections 4.3 through 4.6.

[2]See Section 4.6.

IV-4

4.7 PRESSURE APPARATUS

Because of the large number of samples to be run under pressure, a bank of nine pressure vessels, three for each of the evaluation fluids, was set up. Figure IV-2 shows one group of three vessels. Each is capable of withstanding 20,000 psi pressure safely at 90° C. The material is high strength carbon steel.
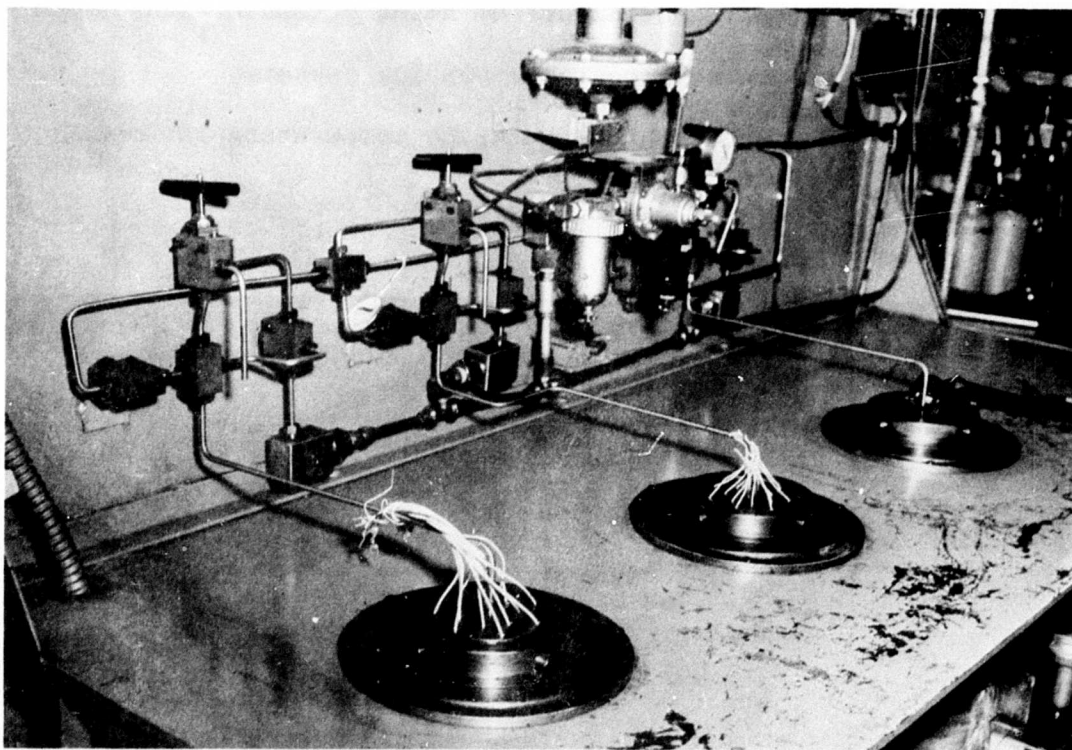
Figure IV-2
Pressure Vessels

The dimensions of the usable inner space are 5 inches in diameter by 12½ inches deep. The pressure-compensating fluids were introduced directly into the pressure vessels and thus served as the pressurizing media. Since water was not introduced into the vessels there was no problem of corrosion of the vessel walls. As previously mentioned, the fluids were also held in sealed polyethylene bags containing the samples of insulation being evaluation. Figure IV-3 is a partial view of the control panel; this portion belonging to the three units shown in figure IV-2 The essential elements of the apparatus are:

• Pressure vessel, with pressure head having connections and penetrations for pressurizing and for pressure and temperature measurement and control.

• Pressurizing pump with fluid reservoir.

• Pressure gage accurate to ± 50 psi.

• Pressure control system using pressure transducer.

• Wraparound electrical heating jacket.

• Thermocouple for measuring temperature inside the vessel.

• Temperature control system.
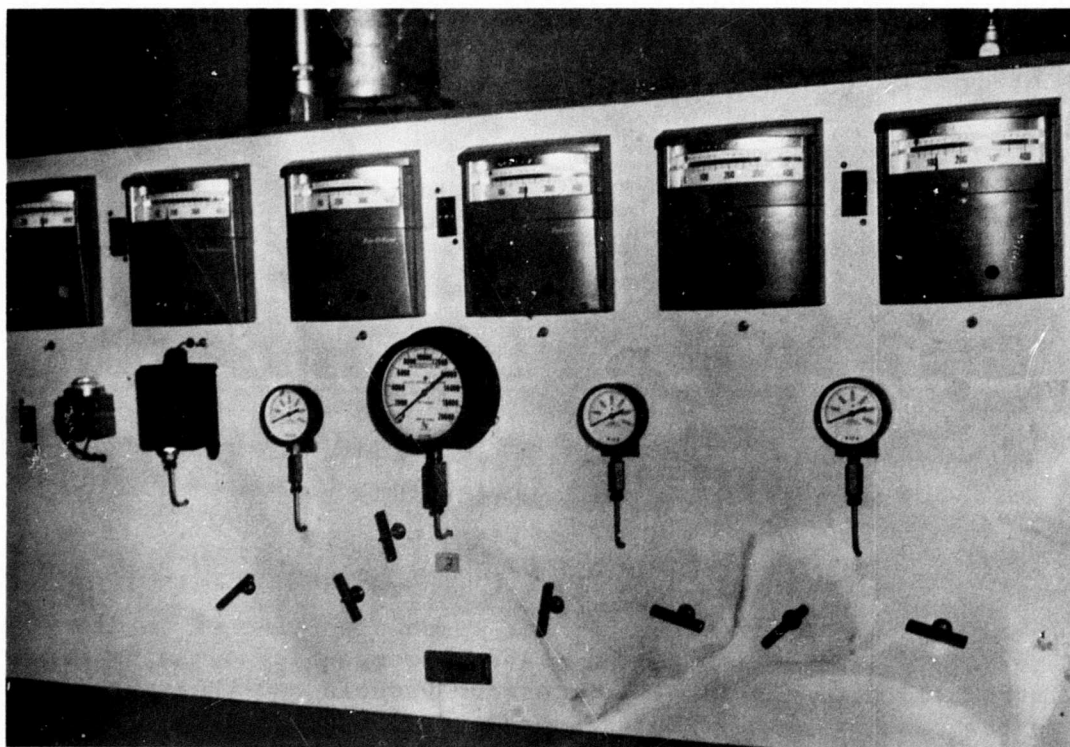
Figure IV-3
Control Panel for Pressure Vessels

4.8 DIELECTRIC BREAKDOWN VOLTAGE MEASUREMENT

All of the insulations in the Center's program, except molding compounds, were evaluated for dielectric quality before and after immersion in the fluids by measuring their dielectric breakdown voltage. The instrumentation used for this is shown in figure IV-4. The output voltage of the unit is variable over a continuous range from 0 to 20 kv at 60 hertz. Voltage is stepped up from 220V, 60 Hz by the transformer. Dielectric breakdown voltages of the various insulations were measured by connecting the high-voltage output across the insulation under test. Voltage was raised automatically, starting from zero, at a steady rate until dielectric breakdown occurred. Breakdown caused a circuit breaker in the primary circuit to trip as soon as its current reached 5 amperes, corresponding to about 54 mA in the output test circuit. At this point the voltage indicator was pinned, which permitted an accurate reading of breakdown voltage. Because this quantity may vary substantially (20% or more) from one sample to another, at least three samples were run for each determination.

1. Oil-filled Transformer   2. Voltmeter

Figure IV-4
High-Voltage Apparatus for Measuring
Dielectric Breakdown Voltage

4.9   SPECIFIC PROCEDURES FOR INDIVIDUAL TYPES OF INSULATION

4.9.1   Magnet Wire Insulation

The sample pieces used were twisted pairs approximately 5 inches long, prepared according to IEEE specification (AIEE specification) No. 57 (January 1959) for round wire. (Magnet wire is already insulating film coated as supplied by the manufacturer.) When film plus varnish was to be evaluated, the twisted pairs were given a single coat of varnish and were cured according to the varnish manufacturer's instructions. Note in table IV-1 that magnet wires having Codes A and B films were evaluated at atmospheric pressure only (see Chapter V, 5.3.2 for further discussion). Ten samples of each of these magnet wires (with film alone and with film plus varnish) were withdrawn from each fluid at each exposure condition for testing at the time intervals stated in Section 4.6. This number was reduced from ten to five with the magnet wires having Codes C, D, and E films, since the numbers of samples were becoming too cumbersome in relation to the amount of information obtained. (For the remaining insulating materials the number was further reduced to three.) Dielectric breakdown voltage measurements and mandrel bend tests were performed on ten or five samples of each insulation, as prepared, not immersed in fluid, to establish base line values prior to immersion. Immersed samples, on withdrawal from fluids at the designated time intervals, were wiped dry with lint-free white paper toweling. They were examined for cracking, loss of adhesion, softening, dissolving, or any other physical deterioration of the insulation. Dielectric breakdown voltage measurements, followed by mandrel bend tests, were then performed on each group of ten or five samples withdrawn. The latter two procedures are described in the following two paragraphs.

4.9.1.1   Dielectric Breakdown Voltage of Magnet Wire Insulation

The twisted pair was placed in a Lexan holder, figure IV-5. The ends of the wires, scraped free of film, were connected to the high voltage terminals of the test apparatus (see Section 4.8) as shown in figure IV-6. Voltage was then raised steadily from 0 volt until breakdown occurred. Breakdown usually took place between contacting surfaces of the two pieces of insulated wire in the twisted portion of the sample.
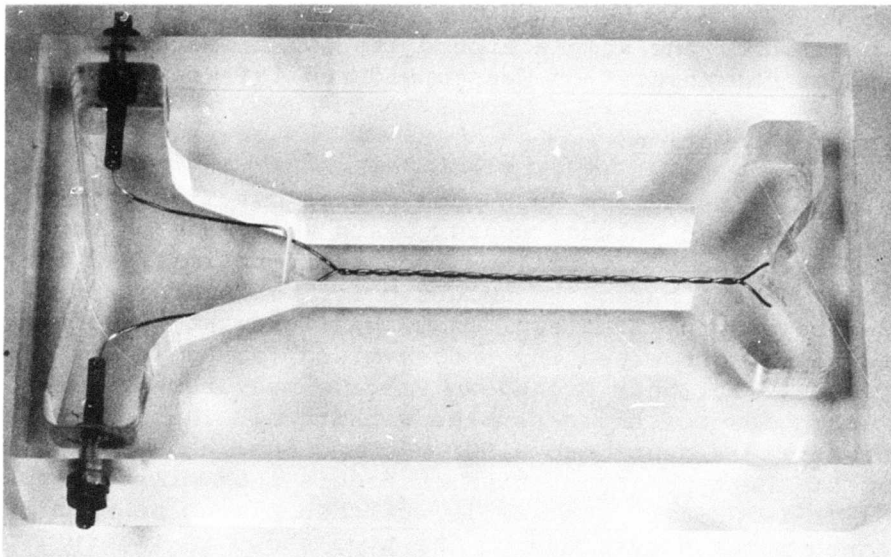
Figure IV-5
Lexan Holder with Twisted Pair in Place
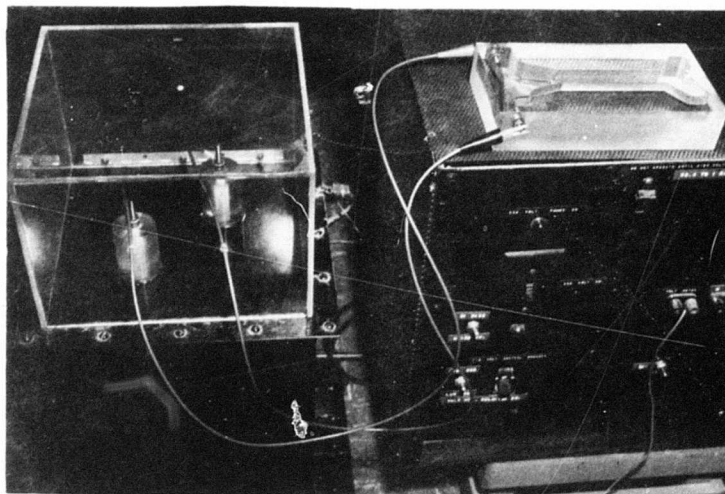
Figure IV-6
Twisted Pair in Lexan Holder Connected
to High-Voltage Test Apparatus

4.9.1.2 Mandrel Bend Test of Magnet Wire

This was performed on each sample after the dielectric breakdown voltage measurement. The procedure was to bend the twisted portion of the sample around its own diameter. Cracking or peeling of the insulation was considered failure.

4.9.2 Sheet Insulation

The samples used were 3x3½-inch pieces cut from stock sheet. Dielectric breakdown voltage measurements were made on three samples of each sheet material as prepared (not immersed in fluid) to establish base line values prior to immersion. Immersed samples, on withdrawal from the fluids at the designated time intervals, were wiped dry and examined for any signs of physical deterioration. Breakdown voltage measurements were then made on each group of three samples withdrawn. The sample being measured was first bent into a 90° V-shape in a hand-manipulated metal jig of the type illustrated in figure 1 of military speci- fication MIL-I-22834A. The sample was then placed between two 90° V-shaped metal electrodes of the type shown in figure 2 of MIL-I-22834A. The electrodes were connected to the high voltage terminals of the test apparatus described in Section 4.8. The voltage was raised steadily from 0 volt until breakdown occurred. Breakdown usually appeared as a pinhole through the sample.

4.9.3 Lead Wire Insulation

The test samples were 10-inch lengths cut from stock spools of wire. Dielectric breakdown voltage measurements were made on three samples of each lead wire as prepared (not immersed in fluid) to establish base line values prior to immersion. Immersed samples, on withdrawal from the fluids at the designated time intervals, were examined for physical deterioration of the insula- tion and were wiped dry, except when the extent of deterioration prevented this. Visual examination included manually flexing the sample to observe any cracking or peeling of the insulation. Dielectric breakdown voltage measurements were made on all groups of three samples withdrawn in which the physical integrity of the insulation permitted it. The procedure is described in the following paragraph.

The sample was held in the same clamp used for sleeving samples, shown in figure IV-7, with the aluminum foil covered jaws of the clamp in contact with the insulation. Each jaw measures 1x2 inches, and under the foil on each jaw is a foam rubber pad, 1/4-inch-thick, to permit close contact between

insulation and foil. The conductor of the lead wire was connected
to one high-voltage terminal of the test apparatus described in
Section 4.8, and the clamp which is in contact with the foil was
connected to the other terminal. Voltage was raised steadily
from 0 volt until breakdown occurred. Breakdown usually appeared
as a pinhole through the insulation.
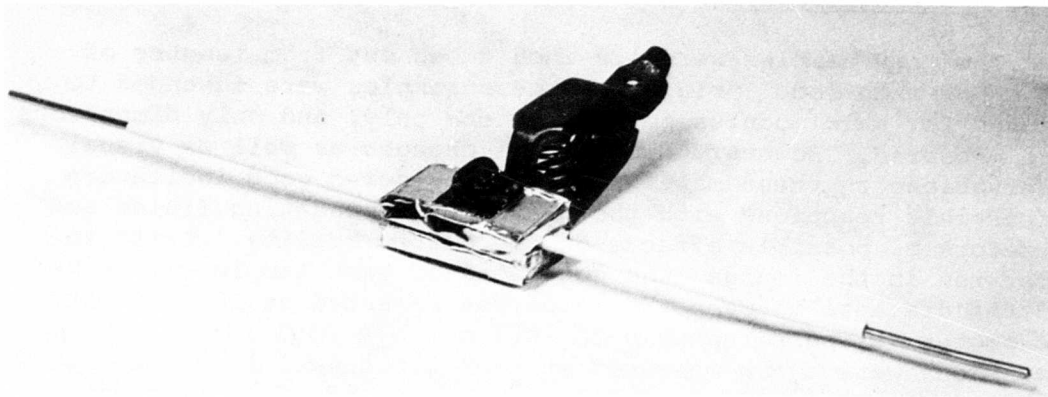
Figure IV-7
Sleeving Sample in Clamp Ready
for Connecting High-Voltage Apparatus

4.9.4 Sleeving

The sample pieces used were 5-inch lengths cut from stock
spools of sleeving. Dielectric breakdown voltage measurements
were made on three samples of each sleeving material as prepared
(not immersed in fluid) to establish base line data prior to
immersion. Immersed samples, on withdrawal from the fluids at
the designated time intervals, were examined for physical
deterioration and were wiped dry, unless the extent of deteriora-
tion prevented it. Visual examination included manually bending
the sample to observe any cracking or splitting. Dielectric
breakdown voltage measurements were made on all groups of three
samples withdrawn from the fluids in which the physical integrity
of the samples permitted. The procedure is described in the
following paragraph.

The sample was slipped over a 1/8-inch-diameter soft aluminum rod approximately 14 inches long (4 inches longer than the sample), and the rod plus sleeving was placed in a clamp shown in figure IV-7 (see description in Section 4.9.3) so that the sleeving was pressed against the rod. The exposed portion of the rod was connected to one terminal of the test apparatus described in Section 4.8, and the clamp was connected to the other terminal. Voltage was raised steadily from 0 volt until breakdown occurred. Breakdown usually appeared as a pinhole through the sleeving.

4.9.5 Molding Compounds

The test samples were 1/2-inch cubes cut from lengths of 1/2 x 1/2-inch rod. Originally these samples were intended to be used for bulk modulus determinations only, and only dimensions were measured. However, dimensional changes as well as visual observations on these materials are considered good indicators of possible reactions with the pressure-compensating fluids and therefore of possible effects on dielectric quality. Prior to immersion in the fluids the cut faces of each sample was marked, and the distance between the faces was measured at $25\pm5°$ C with micrometer calipers readable to ±0.1 mil (±0.0001 inch). These dimensions were again measured at each withdrawal from the fluids at the designated time intervals. The samples of molding compounds, unlike the other insulations evaluated, were all returned to the fluids after each withdrawal and measurement.

4.10 SUGGESTED MODIFICATIONS IN EVALUATION METHODS

It is expected that electrical equipment will continue to be operated in pressure-compensating fluids for the foreseeable future. Since more information could profitably be added to this handbook, even considering only present deep ocean technology needs, it is hoped that further evaluations of electrical insulating materials in fluids will be made. In the course of this Center's evaluations and afterwards, possible improvements in the evaluation procedures became apparent. Modifications to these procedures, as outlined in the following sections, should be considered for future evaluations.

4.10.1 Elimination or Modification of Pressure Testing

An examination of the detailed data tables in Chapter V, for the various insulating materials, shows relatively little difference in results between exposures at 0 and at 13,200 psig at either temperature for any of the materials evaluated (although the effect at 90° C was much greater than at 25° C, as expected).

The value of any further testing at high-pressure seems question-
able. It might be useful to obtain additional data to confirm or
contradict the present results. However, in a situation when
high-pressure equipment is not readily available, an evaluation at
atmospheric pressure, only, would probably be sufficient. If
further work is to be done at high-pressure, it is suggested
that pressure cycling be considered instead of static tests. The
cycle should be designed to simulate submerging and surfacing of
an actual vehicle. This would allow for the possibility of
materials blistering, cracking, delaminating, etc., as might
result from the slow absorption of fluid under high-pressure and
the relatively rapid release to atmospheric pressure on an actual
vehicle.

4.10.2 Addition of Seawater to Test Fluids

See Chapter I, 1.5.3.3 for a discussion of possible hydrol-
sis of insulating materials. The evaluation conditions should
include high-temperature (80°-90° C) tests in which a small
amount of seawater (or synthetic seawater), say 1% to 5% by
volume, is added to the test fluid, especially in evaluating
magnet wire insulations and varnishes. This will provide much
needed data, now almost entirely lacking, in answer to the ques-
tion of possible hydrolysis of insulating materials when seawater
leaks into pressure-compensated enclosures. It is essential
during the test period to keep the seawater vigorously stirred
into the compensating fluid to simulate conditions in a motor
enclosure.

4.10.3 Helical Coil Test for Magnet Wire Insulation

The suggestion has been made* that rather than relying on
twisted pairs for the evaluation of magnet wire insulation coated
with varnish, a helical coil test be used instead.[6] Under this
procedure magnet wire coated with the insulation to be evaluated
is formed into helical coils which are then coated with the
varnish to be evaluated. After the desired exposure period in
the compensating fluid, the coils are subjected to a bend test
which is a measure of the varnish bond strength and indicates
any softening or loss of bond strength by the varnish.

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*By J. F. Tobin of NAVSEC (SEC 6158D).

4.10.4 Other Test Fluids

See Section 4.3 for an explanation of how the three fluids of this Center's evaluations were selected. For the evaluation of insulating materials for specific deep-submergence systems, it would be desirable to use as test fluids the same fluids to be used in those systems. For a continuation of the type of program carried out at this Center, it might be advisable to select a new group of fluids, according to the state-of-the-art of pressure-compensating fluids at such future time.

CHAPTER V
DATA DEVELOPED FOR SPECIFIC MATERIALS

5.1 INSULATIONS EVALUATED IN THIS CENTER'S DOT PROGRAM

Six categories of electrical insulations were studied:
magnet wire film, varnish, sheet material, lead wire insulation,
sleeving, and molding compounds. These comprise the categories
identified in Chapter II, except for laminates. They are further
discussed in Chapters III and IV. From three to six materials in
each of the six categories were selected for evaluation from
existing commercial products. Most of those chosen conform to
one of a number of military specifications. They were selected
as representative of important chemical types in each category
as well as for their known performance in air and the most opti-
mistic expectations of their performance in pressure-compensating
fluids.

5.2 METHODS OF EVALUATION

The general approach and detailed procedures used are
described in Chapter IV.

5.3 DATA TABLES

5.3.1 Organization of the Tables

The individual categories of insulating materials are treated
in five separate sections, 5.4 through 5.9, of this chapter.
Recommendations of materials, and detailed data on which the
recommendations are based, are presented in tables in the various
sections accompanied by explanatory texts. Each section has
first, a table identifying the materials evaluated by name or
code letter and indicating their chemical type and, in the case
of laminated sheet insulation, physical structure. This table
also identifies military specifications with which the individual
materials comply when used in air environments. Next, an "Applica-
tion Guide" lists the materials evaluated in order of preference
for deep-submergence applications in pressure-compensating fluids
with specific statements of their suitability. Negative as well
as positive recommendations are included to warn against materials
known to be unsatisfactory as well as to indicate which are
acceptable. Tables listing the detailed laboratory data from
which the Application Guide was compiled are placed after the
Application Guide.

5.3.2 Interpretation of the Tables

The following points should be noted in using the Application Guides and detailed data tables:

• Magnet wire insulations consisting of Codes A and B film coatings, with and without varnishes, were evaluated at atmospheric pressure only, not at the higher pressure. The data are considered valid for extrapolation to higher pressures, however, because an increase in pressure from atmospheric to 13,200 psi made relatively little difference in the effect of any of the fluids on any of the other insulating materials evaluated. A prior discussion of this point will be found in Chapter IV, Section 4.10.1.

• In the detailed data tables, color changes alone are not considered an indication of failure of an insulation. The significant signs of degradation are considered to be physical deterioration such as softening, cracking embrittlement, peeling and flaking of film coatings and varnishes, delamination of laminated sheet material, and a substantial drop in dielectric breakdown voltage.

• In many instances, the dielectric breakdown voltage of an insulation is greater after exposure to a given fluid than when originally measured in air. This is apparently due to the replacement of air by the compensating fluid which has a higher dielectric breakdown voltage than the air which it replaces.

• The recommendations in the Application Guides apply primarily to the specific insulations evaluated, and caution must be exercised in extrapolating to other materials. For equipment being newly designed, it is suggested that the specific proprietary materials recommended in the Application Guides, or materials known to be of identical chemical structure, be specified. For off-the-shelf equipment items any insulation not identical to a recommended one in this handbook can be rated in its expected performance according to its similarity in chemical structure to a specific recommended material.

5.4 MAGNET WIRE INSULATIONS AND VARNISHES

5.4.1 Materials Evaluated

Magnet wire is generally supplied coated with an insulating film. Its use in military applications in air environments is governed by Federal Specification J-W-001177 (includes detail specification sheets J-W-001177/1, -2, -3, -4, etc.).* In the program at this Center, five magnet wires were selected for evaluation of their suitability in pressure-compensating fluids in deep-submergence applications. Each of the five was evaluated without varnish as well as coated with either two or three of five varnishes. All of these varnishes comply with Military Specification MIL-I-24092A. Table V-1 identifies the materials by code letters and indicates their chemical types and conformance to military specifications.

TABLE V-1
MAGNET WIRE FILMS AND VARNISHES
EVALUATED UNDER DOT PROGRAM

Material	Chemical Type	Navy Designation	Thermal Rating in Air, °C
Magnet Wire Films J-W-001177			
Code A, heavy coating	Polyvinyl formal	Class 105, Type T2	105
Code B, heavy coating	Polyimide	Class 220, Type M2	220
Code C, heavy coating	Epoxy	None	130[1]
Code D, heavy coating	Polyamide-imide coated polyester	Class 180 Type H2	180
Code E[2]	Polyamide-imide	None	220
Varnishes MIL-I-24092A			
Code F	Oil-base phenolic	Type M, Class 130	130
Code G	Polyester	Type M, Class 155	155
Code H	Polyester	Type M, Class 180	180
Code J	Silicone	Type M, Class 200	200
Code K	Epoxy	None	200

[1] This Center's rating.

[2] As of the publication date of this handbook this product may no longer be commercially available.

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*Most recent specification as of this writing. It is suggested that users of this handbook check for possible later revisions or supersessions of any specification referred to herein.

Thermal ratings of magnet wire insulations and varnishes in air
are included in table V-1 because they correlate roughly with the
suitability of the materials in fluids (see table V-2).

TABLE V-2
MAGNET WIRE AND VARNISH APPLICATION GUIDE
FOR DEEP-SUBMERGENCE USE[1,2]

Magnet Wire Film/Varnish Systems[3,4]	Deep-Submergence Applicability in Pressure-Compensating Fluids at Temperatures to 90° C and Pressures to 13,200 psi
Code B Film Polyimide, heavy coating, no varnish	Preferred magnet wire film, good for use in petroleum base and silicone fluids. Hydrolytic stability (see Section 5.4.3 and Chapter I, 1.5.3.3), may be a problem if fluid temperature exceeds 90° C.
Code E Film Heavy coating, no varnish	Fair to good for use in petroleum base and silicone fluids. Best hydrolytic stability of all systems evaluated (see Section 5.4.3 and Chapter I, 1.5.3.3); however, may no longer be available.
Code D Film Heavy coating, no varnish	Fair to good for use in petroleum base and silicone fluids.
Code B Film Polyimide, heavy coating, with Code F varnish	Fair to good for use in petroleum base and silicone fluids.
Code E Film Heavy coating, with Code H varnish	Fair to good for use in silicone fluids; poor to fair for use in petroleum base fluids. May no longer be available as of publication date of this handbook.
Code C Film Heavy coating, no varnish	Fair to good for use in silicone fluids; not recommended for use in petroleum base fluids.
Code A Film Polyvinyl formal, heavy coating, with: no varnish Code F varnish Code G varnish Code B Film Polyimide, heavy coating, with Code G varnish	Acceptable for use in petroleum base or silicone fluids only if temperature of insulation and of fluid does not substantially exceed 25° C.
Code A Film Polyvinyl formal, heavy coating, with Code J varnish Code B Film Polyimide, heavy coating, with Code J varnish Code E Film Heavy coating, with Code K varnish Code D Film Heavy coating, with Code H varnish Code D Film Heavy coating, with Code K varnish Code C Film Heavy coating, with Code H varnish Code C Film Heavy coating, with Code K varnish	Not recommended for use in petroleum base or silicone fluids.

(1) Based on evaluation of materials in three representative pressure-compensating fluids. For detailed data see tables V-3 through V-7.

(2) See Section 5.3.2 for explanatory notes on interpretation of Application Guide.

(3) See table V-1 for chemical and military specification classification of materials and thermal ratings in air.

(4) Listed in order of preference for DOT applications

5.4.2 100% Solids Varnish

This is a relatively new type of material in electrical insulation technology. No varnishes of this type were evaluated under this Center's DOT program except for a very limited evaluation of hydrolytic stability at 132° C. A combination of one 100% solids varnish, a polyester material, over a polyimide magnet wire film was found to have an average life of 281 hours in steam at 132° C and 25 psig.[5,6]

A limited amount of field experience has been obtained with this type of varnish in deep-submergence use. Five 30-hp a-c motor stators were coated with four different 100% solids varnishes, Codes AA, AB, AC, and AD. The motors have been in operation on LOSS in MIL-H-5606B pressure-compensating fluid since 1973 at a depth of 100 feet. The temperature of the stator windings is believed to approach 90° C in some cases. During a 2-year period no problems have been encountered with these units. For a previous discussion of 100% solids varnishes see Chapter II, Section 2.3.4.

5.4.3 Hydrolytic Stability

For a discussion of possible hydrolytic degradation of insulating materials in compensating fluids containing leaked-in seawater see Chapter I, Section 1.5.3.3. Magnet wire film insulation is especially susceptible to this type of deterioration and should therefore be chosen with due regard to possible seawater leakage.

5.4.4 Method of Evaluation

See Chapter IV, 4.9.1 through 4.9.1.2.

5.4.5 Ratings of Magnet Wire Insulations and Varnishes for Deep-Submergence Use

Detailed data for the 5 magnet wire films and the 12 magnet wire film varnish combinations are given in tables V-3 through V-7. Table V-2 gives specific recommendations based on the 17 systems evaluated. In applications in which magnet wire can be used without varnish, as in a low-voltage solenoid, wire having a heavy coating of Code B film is the recommended magnet wire. Where varnish is required, as in motor windings, a heavy coating of Code B film overcoated with Code F varnish is the preferred insulation system. It can be seen that the remaining choices are limited, except as noted in 5.3.2 in the discussion of possible

extrapolation to other materials. See also the discussion of
100% solids varnishes in 5.4.2.

TABLE V-3[1]
DETAILED RESULTS OF 364-DAY IMMERSION OF MAGNET
WIRE TWISTS COATED WITH CODE A FILM, WITH AND
WITHOUT VARNISHES, IN THREE DOT FLUIDS AT
ATMOSPHERIC PRESSURE
(For Recommended Usages see Table V-2, Magnet
Wire Application Guide)

Insulation System	Medium and Time of Exposure	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 10 Measurements	Visual and Physical Examination
Code A film (polyvinyl formal), heavy coating, no varnish	Air, initial condition	25+5	10.4	Normal
	364 days in VV-I-530 fluid	25+5	7.6	No detectable change
		90	8.8	Film very brittle and discolored
	364 days in MIL-H-6083C fluid	25+5	9.0	No detectable change
		90	7.6	Film brittle and discolored
	364 days in 1 cSt silicone fluid	25+5	8.3	Copper discolored
		90	7.7	Film brittle, breaks on handling; copper discolored
Code A film (polyvinyl formal), heavy coating, with Code F varnish	Air, initial condition	25+5	12.0	Normal
	364 days in VV-I-530 fluid	25+5	12.1	No detectable change
		90	7.9	Varnish breaks off when handled; copper discolored
	364 days in MIL-H-6083C fluid	25+5	12.0	No detectable change
		90	10.7	Varnish and film brittle; copper discolored
	364 days in 1 cSt silicone fluid	25+5	12.8	Copper discolored
		90	8.5	Varnish and film brittle; varnish breaks off when handled
Code A film (polyvinyl formal), heavy coating, with Code G varnish	Air, initial condition	25+5	10.7	Normal
	364 days in VV-I-530 fluid	25+5	12.6	No detectable change
		90	9.7	Film and varnish brittle; copper discolored
	364 days in MIL-H-6083C fluid	25+5	13.2	No detectable change
		90	8.4	Varnish slightly soft; film brittle
	364 days in 1 cSt silicone fluid	25+5	12.8	Copper discolored
		90	11.6	Varnish slightly soft, breaks when handled; copper discolored
Code A film (polyvinyl formal), heavy coating, with Code J varnish	Air, initial condition	25+5	11.1	Normal
	364 days in VV-I-530 fluid	25+5	9.5	Varnish very soft, film or varnish discolored
		90	9.5	Varnish and film brittle; varnish unusually black
	364 days in MIL-H-6083C fluid	25+5	10.3	Varnish slightly soft, breaks off when handled;
		90	8.5	Varnish slightly soft, breaks off when handled; varnish and film discolored
	364 days in 1 cSt silicone fluid	25+5	9.6	Varnish slightly soft
		90	7.9	Varnish slightly soft; copper ends discolored

[1] See Section 5.3.2 for comments on interpretation of tables.

TABLE V-4[1]
DETAILED RESULTS OF 364-DAY IMMERSION OF MAGNET WIRE TWISTS COATED WITH CODE A FILM, WITH AND WITHOUT VARNISHES IN THREE DOT FLUIDS AT ATMOSPHERIC PRESSURE
(For Recommended Usages see Table V-2, Magnet Wire Application Guide)

Insulation System	Medium and Time of Exposure	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 10 Measurements	Visual and Physical Examination
Code B film (polyimide), heavy coating, no varnish	Air, initial condition	25±5	11.1	Normal
	364 days in VV-I-530 fluid	25±5	9.4	Copper discolored
		90	11.0	Film discolored
	364 days in MIL-H-6083C fluid	25±5	10.5	No detectable change
		90	10.2	Slightly soft, film and copper discolored
	364 days in 1 cSt silicone fluid	25±5	9.9	Copper discolored
		90	9.3	Copper discolored
Code B film (polyimide), heavy coating, with Code F varnish	Air, initial condition	25±5	12.7	Normal
	364 days in VV-I-530 fluid	25±5	14.3	No detectable change
		90	15.3	Varnish and copper discolored
	364 days in MIL-H-6083C fluid	25±5	14.2	No significant change
		90	16.1	Slightly soft, film or varnish discolored, copper discolored
	364 days in 1 cSt silicone fluid	25±5	14.2	Copper discolored
		90	13.5	Copper discolored
Code B film (polyimide), heavy coating, with Code G varnish	Air, initial condition	25±5	13.1	Normal
	364 days in VV-I-530 fluid	25±5	11.8	No detectable change
		90	11.8	Varnish and copper discolored
	364 days in MIL-H-6083C fluid	25±5	12.3	No detectable change
		90	11.1	Varnish brittle and discolored, copper discolored
	364 days in 1 cSt silicone fluid	25±5	14.7	Copper discolored
		90	14.5	Varnish slightly soft and breaks off when bent, copper discolored
Code B film (polyimide), heavy coating, with Code J varnish	Air, initial condition	25±5	12.7	Normal
	364 days in VV-I-530 fluid	25±5	10.0	Slightly soft
		90	10.9	Varnish and copper discolored
	364 days in MIL-H-6083C fluid	25±5	9.7	Varnish slightly soft
		90	11.8	Varnish soft and tacky, peels off when voltage applied
	364 days in 1 cSt silicone fluid	25±5	9.9	Varnish very soft
		90	10.5	Varnish slightly soft, copper discolored

[1] See Section 5.3.2 for comments on interpretation of tables.

TABLE V-5[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF MAGNET WIRE TWISTS COATED WITH CODE C FILM, WITH AND WITHOUT VARNISHES IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usages see Table V-2, Magnet Wire Application Guide)

Insulation System	Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 5 Measurements	Visual and Physical Examination
Code C film, heavy coating, no varnish	Air, initial condition	0	25±5	10.0	Normal
	240 days in VV-I-530 fluid	0	25±5	9.6	No detectable change
			90	3.6	Film flakes off
		13,200	25±5	10.3	No detectable change
			90	6.4	Film brittle, cracked, flakes off; failed mandrel bend test
	240 days in MIL-H-6083C fluid	0	25±5	10.4	No detectable change
			90	7.8	No detectable change
		13,200	25±5	9.2	No detectable change
			90	5.0	Film flakes off; failed mandrel bend test; copper discolored
	240 days in 1 cSt silicone fluid	0	25±5	10.0	No detectable change
			90	8.0	No detectable change
		13,200	25±5	8.2	No detectable change
			90	3.9	No detectable change
Code C film, heavy coating, with Code K varnish	Air, initial condition	0	25±5	10.1	Normal
	240 days in VV-I-530 fluid	0	25±5	6.7	Varnish brittle; cracked; failed mandrel bend test
			90	7.1	Varnish brittle; cracked; failed mandrel bend test
		13,200	25±5	9.3	Brittle; cracked
			90	8.9	Very brittle; cracked
	240 days in MIL-H-6083C fluid	0	25±5	6.8	Varnish brittle, cracked, flakes off; failed mandrel bend test
			90	8.7	Varnish brittle, cracked, flakes off; failed mandrel bend test
		13,200	25±5	10.2	Brittle, cracked
			90	9.5	Brittle, varnish flakes off; failed mandrel bend test; copper discolored
	240 days in 1 cSt silicone fluid	0	25±5	9.2	Varnish brittle, cracked flakes off; failed mandrel bend test
			90	9.4	Varnish brittle
		13,200	25±5	9.7	Brittle, cracked
			90	9.6	Tacky after 30 days; varnish flaking off; failed mandrel bend test
Code C film, heavy coating, with Code H varnish	Air, initial condition	0	25±5	13.7	Normal
	240 days in VV-I-530 fluid	0	25±5	1.0	No detectable change
			90	4.3	Cracked, varnish flakes off; failed mandrel bend test
		13,200	25±5	10.7	Brittle
			90	9.7	Tacky after 30 days; brittle, failed mandrel bend at end of test
	240 days in MIL-H-6083C fluid	0	25±5	8.3	Failed mandrel bend test
			90	8.4	Very soft; varnish peels or flakes off
		13,200	25±5	9.4	Slightly brittle; varnish flakes off
			90	10.5	Tacky after 60 and 120 days; flakes off; failed mandrel bend at end of test
	240 days in 1 cSt silicone fluid	0	25±5	9.9	Failed mandrel bend test
			90	15.9	No detectable change
		13,200	25±5	10.6	Brittle after 120 days; tacky at end of test
			90	9.3	Tacky after 30 days; varnish flakes off; failed mandrel bend at end of test

[1] See Section 5.3.2 for comments on interpretation of tables.

TABLE V-6[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF MAGNET WIRE TWISTS COATED WITH CODE D FILM, WITH AND WITHOUT, VARNISHES IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usages see Table V-2, Magnet Wire Application Guide)

Insulation System	Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 5 Measurements	Visual and Physical Examination
Code D film, heavy coating, no varnish	Air, initial condition	0	25±5	14.2	Normal
	240 days in VV-I-530 fluid	0	25±5	14.9	No detectable change
			90	8.7	No detectable change
		13,200	25±5	9.3	No detectable change
			90	15.6	Copper discolored
	240 days in MIL-H-6083C fluid	0	25±5	11.6	No detectable change
			90	9.8	No detectable change
		13,200	25±5	9.9	No detectable change
			90	10.3	Copper discolored
	240 days in 1 cSt silicone fluid	0	25±5	13.1	No detectable change
			90	11.0	No detectable change
		13,200	25±5	11.8	No detectable change
			90	10.7	No detectable change
Code D film, heavy coating, with Code K varnish	Air, initial condition	0	25±5	12.5	Normal
	240 days in VV-I-530 fluid	0	25±5	7.9	Failed mandrel bend test
			90	8.1	Varnish brittle, flakes off; failed mandrel bend test
		13,200	25±5	10.6	Brittle, cracked, varnish flakes off
			90	15.6	Tacky after 30 days; brittle at end of test period
	240 days in MIL-H-6083C fluid	0	25±5	10.1	Varnish flakes off; failed mandrel bend test
			90	9.9	Varnish brittle, cracked slightly; failed mandrel bend test
		13,200	25±5	9.6	Brittle, flakes off
			90	11.0	Cracked, copper discolored
	240 days in 1 cSt silicone fluid	0	25±5	9.3	Varnish brittle, cracked slightly; failed mandred bend test
			90	13.2	Varnish brittle, failed mandrel bend test
		13,200	25±5	9.6	Brittle, cracked, flakes off
			90	9.5	Cracked, failed mandrel bend test
Code D film, heavy coating, with Code H varnish	Air, initial condition	0	25±5	17.1	Normal
	240 days in VV-I-530 fluid	0	25±5	0.9	No detectable change
			90	7.9	Cracked slightly, failed mandrel bend test
		13,200	25±5	10.1	Tacky
			90	16.9	Tacky after 30 days, brittle at end of test; copper discolored
	240 days in MIL-H-6083C fluid	0	25±5	8.6	Failed mandrel bend test
			90	9.1	Very soft; varnish peels off readily; failed mandrel bend test
		13,200	25±5	9.3	No detectable change
			90	9.5	Tacky, copper discolored
	240 days in 1 cSt silicone fluid	0	25±5	9.2	Varnish brittle, failed mandrel bend test
			90	14.9	No detectable change
		13,200	25±5	10.5	No detectable change
			90	11.1	Tacky

(1) See Section 5.3.2 for comments on interpretation of tables.

TABLE V-7[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF MAGNET WIRE TWISTS COATED WITH CODE E FILM, WITH AND WITHOUT, VARNISHES IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usages see Table V-2, Magnet Wire Application Guide)

Insulation System	Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 5 Measurements	Visual and Physical Examination
Code E film, heavy coating, no varnish	Air, initial condition	0	25±5	B.6	Normal
	240 days in VV-I-530 fluid	0	25±5	9.9	No detectable change
			90	8.5	No detectable change
		13,200	25±5	9.1	No detectable change
			90	8.5	No detectable change
	240 days in MIL-H-6083C fluid	0	25±5	9.0	No detectable change
			90	8.2	Failed mandrel bend test
		13,200	25±5	8.6	No detectable change
			90	11.3	Copper discolored
	240 days in 1 cSt silicone fluid	0	25±5	10.2	No detectable change
			90	8.5	Brittle, failed mandrel bend test
		13,200	25±5	10.2	No detectable change
			90	8.2	No detectable change
Code E film, heavy coating, with Code K varnish	Air, initial condition	0	25±5	8.7	Normal
	240 days in VV-I-530 fluid	0	25±5	7.4	Cracked slightly; failed mandrel bend test
			90	8.2	Cracked slightly; varnish flakes off; failed mandrel bend test
		13,200	25±5	9.8	Varnish brittle; flakes off
			90	11.4	No detectable change
	240 days in MIL-H-6083C fluid	0	25±5	7.5	Cracked slightly; failed mandrel bend test
			90	9.3	Failed mandrel bend test
		13,200	25±5	8.2	Brittle, varnish flakes off
			90	9.5	Copper discolored
	240 days in 1 cSt silicone fluid	0	25±5	8.4	Cracked slightly; varnish flakes off; failed mandrel bend test
			90	8.9	Varnish brittle, failed mandrel bend test
		13,200	25±5	9.2	Brittle, varnish flakes off
			90	9.0	No detectable change
Code E film, heavy coating, with Code H varnish	Air, initial condition	0	25±5	12.9	Normal
	240 days in VV-I-530 fluid	0	25±5	0.9	No detectable change
			90	8.9	No detectable change
		13,200	25±5	8.1	No detectable change
			90	13.5	No detectable change
	240 days in MIL-H-6083C fluid	0	25±5	6.7	Failed mandrel bend test
			90	7.9	Varnish very soft, peels off readily
		13,200	25±5	11.3	No detectable change
			90	9.2	Tacky, copper discolored
	240 days in 1 cSt silicone fluid	0	25±5	11.9	No detectable change
			90	12.3	No detectable change
		13,200	25±5	10.3	Tacky
			90	9.8	No detectable change

[1] See Section 5.3.2 for comments on interpretation of tables

5.5 SHEET INSULATING MATERIAL

5.5.1 Materials Evaluated

The use of sheet insulating materials for naval applications in air environments is governed by military specifications as follows:*

- MIL-I-24204   Polyamide paper.

- MIL-I-22834A   Plastic film and synthetic fiber mat laminated insulation.

- MIL-I-631D   Nonrigid synthetic resin composition insulation.

- MIL-I-3505C   Electrical insulation sheet and tape.

In the DOT program at this Center, six representative sheet materials were selected for evaluation. As shown in table V-8 five of these conform to the military specifications listed above (for use in air), and one is a nonspecification product.

TABLE V-8
SHEET INSULATING MATERIALS EVALUATED
UNDER DOT PROGRAM

Material	Physical Form and Chemical Type	Conforms to Military Specification	Nominal Thickness In.	Required Dielectric Strength per Indicated Military Specification, KV
Code L	Polyamide paper	MIL-I-24204	0.007	4.20
Code M	Polyimide—glass cloth	None	0.007	-
Code N	Polyethylene terephthalate (polyester) mat-film-mat	MIL-I-22834A, type D100-353	0.0135	13.5
Code O	Polyethylene terephthalate (polyester) film	MIL-I-631D, type G	0.0075	12.0
OVMG	Organic (nonsilicone) varnish-mica-glass	MIL-I-3505C, Class B, type Gmg	0.012	7.80
SVMG	Silicone varnish-mica-glass	MIL-I-3505C, Class H, type Gmg	0.012	6.00

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*Most recent specifications as of this writing. It is suggested that users of this handbook check for possible later revisions or supersessions of any specification referred to herein.

5.5.2 Method of Evaluation

See Chapter IV, 4.9.2.

5.5.3 Ratings of Sheet Insulations for Deep-Submergence Use

Table V-9 gives specific recommendations based on the
evaluations. Detailed data from the evaluation of the six sheet
insulating materials are presented in tables V-10 through V-15.

TABLE V-9

SHEET INSULATING MATERIAL APPLICATION GUIDE

FOR DEEP-SUBMERGENCE USE[1,2]

Material[3,4]	Physical Form and Chemical Type	Deep-Submergence Applicability in Pressure-Compensating Fluids at Temperatures to 90° C and Pressures to 13,200 psi
Code L	Polyamide paper	Preferred sheet material for use in petroleum base and silicone fluids
Code M	Polyimide-glass cloth	Good for use in petroleum base and silicone
Code N	Polyethylene terephthalate (polyester) mat-film-mat	fluids, but may have some tendency to degrade by hydrolysis[5] if water is present
Code O	Polyethylene terephthalate (polyester) film	and if fluid temperature is 90° C or higher.
OVMG	Organic (nonsilicone) varnish-mica-glass	Not recommended for use in petroleum base or silicone fluids because of its tendency
SVMG	Silicone varnish-mica-glass	to delaminate.

(1) Based on evaluation of materials in three representative pressure-compensating fluids. For detailed immersion data see tables V-10 through V-15.

(2) See 5.3.2 for comments on interpretation of Application Guides.

(3) For military specification classification of materials see table V-8.

(4) Listed in order of preference for DOT applications.

(5) See Chapter I, 1.5.3.3.

TABLE V-10[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE L POLYAMIDE INSULATING PAPER IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usages see Table V-9, Sheet Insulating Material Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	6.0	Normal
240 days in VV-I-530 fluid	0	25±5	11.2	No observable change
		90	10.7[2]	No observable change
	13,200	25±5	9.6[2]	No observable change
		90	11.7[2]	Gray in color
240 days in MIL-H-6083C fluid	0	25±5	10.2	No observable change
		90	11.1[2]	General brown discoloration
	13,200	25±5	11.2	No observable change
		90	11.5[2]	Darkened in color
240 days in 1 cSt silicone fluid	0	25±5	8.7	No observable change
		90	7.9	No observable change
	13,200	25±5	13.8	No observable change
		90	14.4	No observable change

[1] See 5.3.2 for comments on interpretation of tables.

[2] Failed by tracking around edges of sheet sample rather than through the sheet on one or more samples. This indicates that the true dielectric breakdown voltage may be higher than the value shown.

TABLE V-11[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE M POLYIMIDE-GLASS CLOTH INSULATION IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usages see Table V-9, Sheet Insulating Material Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	7.6	Normal
240 days in VV-I-530 fluid	0	25±5	10.7	
		90	10.9	
	13,200	25±5	10.9[2]	
		90	11.4[2]	
240 days in MIL-H-6083C fluid	0	25±5	10.2	No observable change under any of the exposure conditions.
		90	10.5	
	13,200	25±5	11.5[2]	
		90	11.4[2]	
240 days in 1 cSt silicone fluid	0	25±5	10.2[2]	
		90	10.6[2]	
	13,200	25±5	9.6[2]	
		90	10.7	

[1] See 5.3.2 for comments on interpretation of tables.

[2] Failed by tracking around edges of sheet sample rather than through the sheet on one or more samples. This indicates that the true dielectric breakdown voltage may be higher than the value shown.

TABLE V-12[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE N POLYESTER MAT-FILM-MAT INSULATING SHEET IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usages see TABLE V-9, Sheet Insulating Material Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25 ± 5	14.6	Normal
240 days in VV-I-530 fluid	0	25 ± 5	$13.7^{(2)}$	No observable change
		90	$13.6^{(2)}$	General brown discoloration
	13,200	25 ± 5	$13.7^{(2)}$	No observable change
		90	$13.2^{(2)}$	General yellow discoloration
240 days in MIL-H-6083C fluid	0	25 ± 5	$13.5^{(2)}$	No observable change
		90	$13.9^{(2)}$	General brown discoloration
	13,200	25 ± 5	$14.0^{(2)}$	No observable change
		90	$14.2^{(2)}$	Color darkened
240 days in 1 cSt silicone fluid	0	25 ± 5	$13.7^{(2)}$	No observable change
		90	$13.4^{(2)}$	General brown discoloration
	13,200	25 ± 5	$13.8^{(2)}$	No observable change
		90	$14.4^{(2)}$	General yellow discoloration

(1) See 5.3.2 for comments on interpretation of tables.

(2) Failed by tracking around edges of sheet sample rather than through the sheet on one or more samples. This indicates that the true dielectric breakdown voltage may be higher than the value shown.

TABLE V-13[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE O POLYESTER FILM INSULATION IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usages see Table V-9, Sheet Insulating Material Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	6.5[2]	Normal
240 days in VV-I-530 fluid	0	25±5	13.6[2]	No observable change under any of the exposure conditions.
		90	13.5[2]	
	13,200	25±5	13.5[2]	
		90	13.5[2]	
240 days in MIL-H-6083C fluid	0	25±5	13.5[2]	
		90	13.8[2]	
	13,200	25±5	13.7[2]	
		90	14.0[2]	
240 days in ⁀ cSt silicone fluid	0	25±5	12.6[2]	
		90	13.6[2]	
	13,200	25±5	13.4[2]	
		90	13.2[2]	

[1] See 5.3.2 for comments on interpretation of tables.

[2] Failed by tracking around edges of sheet sample rather than through the sheet on one or more samples. This indicates that the true dielectric breakdown voltage may be higher than the value shown.

TABLE V-14[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF OVMG, ORGANIC (NONSILICONE) VARNISH-MICA-GLASS SHEET INSULATING MATERIAL IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usages see Table V-9, Sheet Insulating Material Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	10.1[2]	Normal
240 days in VV-I-530 fluid	0	25±5	12.2[2]	Very soft, flaking, delaminating
		90	11.4	Delaminating, mica splitting and separating after 30 days; swollen, delaminating, no binder after 60 days
	13,200	25±5	11.9[2]	Delaminating after 120 days
		90	8.9[2]	Darkened in color, delaminating after 120 days
240 days in MIL-H-6083C fluid	0	25±5	8.3[2]	Mica splitting and separating
		90	12.1[2]	General brown discoloration, mica splitting and separating after 1 day; delaminating after 30 days; very soft after 60 days
	13,200	25±5	10.5	Delaminating after 120 days
		90	10.9	Darkened in color after 60 days; delaminating after 120 days
240 days in 1 cSt silicone fluid	0	25±5	9.5	Swollen, delaminating, no binder in mica and glass after 120 days
		90	11.9	Material stiffened
	13,200	25±5	7.9[2]	Delaminating after 120 days
		90	12.0[2]	Yellow discoloration, delaminating after 120 days

[1] See 5.3.2 for comments on interpretation of tables.

[2] Failed by tracking around edges of sheet sample rather than through the sheet on one or more samples. This indicates that the true dielectric breakdown voltage may be higher than the value shown.

TABLE V-15[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF SVMG, SILICONE VARNISH-MICA-GLASS SHEET INSULATING MATERIAL IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usages see Table V-9, Sheet Insulating Material Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	12.6	Normal
240 days in VV-I-530 fluid	0	25±5	13.8[2]	Delaminating after 120 days; very soft and flaking after 240 days
		90	14.5[2]	Delaminating, mica splitting and separating after 30 days; swollen, no binder in mica and glass after 60 days
	13,200	25±5	14.7[2]	No observable change
		90	15.3[2]	Delaminating, darkened in color after 120 days
240 days in MIL-H-6083C fluid	0	25±5	13.0[2]	Delaminating after 60 days; very soft and flaking after 120 days
		90	15.4[2]	Mica splitting and separating after 1 day; delaminating after 30 days; very soft and flaking after 60 days
	13,200	25±5	11.6[2]	Delaminating after 120 days
		90	15.1[2]	Delaminating after 1 day
240 days in 1 cSt silicone fluid	0	25±5	13.0[2]	Delaminating after 120 days
		90	10.6[2]	Delaminating after 30 days; soft and flaking after 120 days
	13,200	25±5	11.5[2]	Delaminating after 1 day
		90	14.9[2]	Delaminating, soft after 1 day

[1] See 5.3.2 for comments on interpretation of tables.

[2] Failed by tracking around edges of sheet sample rather than through the sheet on one or more samples. This indicates that the true dielectric breakdown voltage may be higher than the value shown.

5.6 LEAD WIRE INSULATION

5.6.1 Materials Evaluated

High-temperature insulated electrical lead wire is used extensively in Navy applications in air environments. Its required quality and performance for such usage is governed by Military Specifications MIL-W-16878 with detail specifications MIL-W-16878/1, -/2, -/2A, -3, etc., and MIL-W-22759D.* In the DOT program at this Center, three selected lead wires were evaluated for their suitability in pressure-compensating fluids under deep-submergence conditions. Table V-16 identifies the three lead wires and gives the chemical types of the insulating materials and military specification conformance. Because of funding and time limitations, a number of important insulating types were not evaluated in the present program but would be of interest in future studies. These include fluorinated ethylene-propylene polymer (FEP), polyvinylidene fluoride, polyvinyl chloride (PVC), and polyamides.

TABLE V-16
INSULATED LEAD WIRES EVALUATED UNDER DOT PROGRAM

Lead Wire	Insulation, Chemical Type	Conforms to Military Specification	Closest AWG Size	Required Dielectric Strength in Air After 4-hour Soak in Water at 25+5° C
Code P - insulated	Fluorocarbon polymer (polytetrafluoroethy-lene)	MIL-W-16878/4A (type E, 200° and 260° C, 600 volts)	22	2.0 kv (minimum)
Code Q	Silicone rubber	MIL-W-16878/8 (type FF, 200° C, 1000 volts)	16	3.0 kv (minimum)
Code R	Neoprene	None (Manufacturer rates insulation at 90° C maximum, 600 volts maximum)	18	-

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*See footnote on page V-11.

5.6.2 Method of Evaluation

See Chapter IV, 4.9.3.

5.6.3 Ratings of Lead Wire Insulations for Deep-Submergence Use

Table V-17 gives specific recommendations based on evalua-
tions. Detailed data from the evaluation of the three selected
lead wires in pressure-compensating fluids are presented in
tables V-18, V-19, and V-20. Note that only the Code P insulation
is considered satisfactory. As noted above, however, a number
of important materials were not examined. With regard to future
studies, it is expected that other fluorocarbon polymers (notably
FEP and polyvinylidene fluoride) and polyamides will be found to
be acceptable. PVC is a questionable performer, especially at
the higher temperatures, based on present limited knowledge and
should be evaluated along with FEP, polyvinylidene fluoride, and
polyamides.

TABLE V-17
INSULATED ELECTRICAL LEAD WIRE APPLICATION
GUIDE FOR DEEP-SUBMERGENCE USE[1,2]

Lead Wire[3,4]	Insulation Chemical Type	Deep-Submergence Applicability in Pressure-Compensating Fluids at Temperatures to 90° C and Pressures to 13,200 psi
Code P insulated	Polytetrafluoroethylene	Satisfactory for use in petroleum base and silicone fluids
Code R	Neoprene	Not recommended for use in petroleum base fluids; acceptable for use in silicone fluids only if temperature of insulation and of fluid remains near 25° C
Code Q	Silicone rubber	Not recommended for use in petroleum base or silicone fluids

[1] Based on evaluation of lead wires in three representative pressure-compensating fluids. For detailed data see tables V-18 through V-20.

[2] See 5.3.2 for comments on interpretation of Application Guides.

[3] For military specification classification of materials see table V-16.

[4] Listed in order of preference for DOT applications.

TABLE V-18[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE P (POLYTETRAFLUOROETHYLENE)—INSULATED ELECTRICAL LEAD WIRE IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usage see Table V-17, Insulated Electrical Lead Wire Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	8.4	Normal
240 days in VV-I-530 fluid	0	25±5	15.9	No observable change under any of the exposure conditions.
		90	15.0	
	13,200	25±5	15.4	
		90	19.0	
240 days in MIL-H-6083C fluid	0	25±5	15.1	
		90	15.7	
	13,200	25±5	13.4	
		90	18.3	
240 days in 1 cSt silicone fluid	0	25±5	13.8	
		90	12.9	
	13,200	25±5	15.2	
		90	14.3	

[1] See 5.3.2 for comments on interpretation of tables.

TABLE V-19[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE Q (SILICONE RUBBER INSULATED) ELECTRICAL LEAD WIRE IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usage see Table V-17, Insulated Electrical Lead Wire Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	>20.0	Normal
240 days in VV-I-530 fluid	0	25±5	>20.0	Insulation is swollen, elongated, and/or soft and adhesion to wire is nil under all exposure conditions
		90	>20.0	
	13,200	25±5	>20.0	
		90	(2)	
240 days in MIL-H-6083C fluid	0	25±5	(2)	
		90	(2)	
	13,200	25±5	18.9	
		90	(2)	
240 days in 1 cSt silicone fluid	0	25±5	(2)	
		90	(2)	
	13,200	25±5	18.0	
		90	(2)	

[1] See 5.3.2 for comments on interpretation of tables.
[2] Insulation was too severely degraded to make dielectric breakdown measurements.

TABLE V-20[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE R
(NEOPRENE INSULATED) ELECTRICAL LEAD WIRE
IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usage see Table V-17, Insulated
Electrical Lead Wire Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	>20.0	Normal
240 days in VV-I-530 fluid	0	25±5	>20.0	Insulation is swollen and slightly soft
		90	>20.0	Insulation is swollen and soft, and adhesion to wire is nil
	13,200	25±5	>20.0	Insulation is swollen and adhesion to wire is nil
		90	>20.0	Insulation is swollen and adhesion to wire is nil
240 days in MIL-H-6083C fluid	0	25±5	(2)	Insulation is swollen and soft
		90	>20.0	Insulation is swollen and adhesion to wire is nil
	13,200	25±5	>20.0	Insulation is slightly swollen and adhesion to wire is nil
		90	>20.0	Insulation is swollen and elongated, and adhesion to wire is nil
240 days in 1 cSt silicone fluid	0	25±5	>20.0	No observable change
		90	(2)	Insulation is swollen, and adhesion to wire is nil
	13,200	25±5	>20.0	No observable change
		90	>20.0	Insulation is hard and brittle

(1) See 5.3.2 for comments on interpretation of tables.

(2) Insulation was too severely degraded to make dielectric breakdown measurements.

5.7 SLEEVING

5.7.1 Materials Evaluated

The use of electrical insulating sleeving for naval applications in air environments is governed by military specification MIL-I-003190C (includes detail specification sheets MIL-I-003190C/1, -/2, -/3, -/4, -/5, -/6, and -7). See table V-21.* This specification supersedes MIL-I-3190B (21 February 1957), MIL-I-3042A (19 June 1962), MIL-I-21557B (19 July 1963), and MIL-I-18057A (6 February 1957). In this Center's DOT program, five sleevings were selected for evaluation, as shown in table V-21. As with other insulating materials, funding and time limitations made it impractical to investigate all possible chemical types of sleeving.

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*See footnote on page V-3.

TABLE V-21
ELECTRICAL INSULATION SLEEVINGS EVALUATED
UNDER DOT PROGRAM

Sleeving	Chemical Type	Temperature Rating in Air, °C	Conformance to MIL-I-003190C
Code S	Acrylic resin-impregnated glass braid	155	*
Code T	Acrylic resin-impregnated glass braid	155	*
Code U	Polytetrafluorethylene-impregnated glass braid	260	Does not conform
Code V	Polyvinyl chloride-impregnated glass braid	130	*
Code W	Silicone rubber-impregnated glass braid	220	Does not conform

*This material does not appear on the qualified products list, QPL-003190-4 of 19 April 1974; however, the manufacturer indicates that it meets MIL-I-003190C requirements.

5.7.2 Method of Evaluation

See Chapter IV, 4.9.4.

5.7.3 Ratings of Sleevings for Deep-Submergence Use

Table V-22 gives specific recommendations based on evaluations. Detailed data from the evaluation of the five selected sleevings in pressure-compensating fluids are presented in tables V-23 through V-27. Only the Code S sleeving is considered acceptable, although as noted under 5.7.1 not all possible chemical types of sleeving have been investigated. Other sleevings that would be of interest in future studies include polyimide-glass, epoxy-glass, and additional fluorocarbon polymer-glass materials, besides the Code U sleeving already evaluated.

TABLE V-22
ELECTRICAL INSULATION SLEEVING APPLICATION GUIDE FOR DEEP-SUBMERGENCE USE[1,2]

Sleeving[3,4]	Chemical Type	Deep-Submergence Applicability in Pressure-Compensating Fluids at Temperatures to 90° C and Pressures to 13,200 psig
Code S	Acrylic-glass	Satisfactory for use in petroleum base and silicone fluids
Code T	Acrylic-glass	
Code U	Polytetrafluoroethylene-glass	Not recommended for use in petroleum base or silicone fluids
Code V	Polyvinyl chloride-glass	
Code W	Silicone rubber	

[1] Based on evaluation of sleevings in 3 representative pressure-compensating fluids; for detailed data, see tables V-23 through V-27.

[2] See 5.3.2 for comments on interpretation of Application Guides.

[3] For military specification classification of materials see table V-21.

[4] Listed in order of preference for DOT applications.

TABLE V-23[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE S SLEEVING IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usage see Table V-22, Sleeving Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	8.9	Normal
240 days in VV-I-530 fluid	0	25±5	9.2	No observable change
		90	14.9	Color had darkened
	13,200	25±5	12.6	Color had darkened
		90	6.6	Stiff, color had darkened
240 days in MIL-H-6083C fluid	0	25±5	6.5	No observable change
		90	10.0	Color had turned yellow
	13,200	25±5	8.3	No observable change
		90	6.6	Color had darkened
240 days in 1 cSt silicone fluid	0	25±5	7.4	No observable change
		90	5.2	No observable change
	13,200	25±5	7.8[2]	No observable change
		90	11.2	No observable change

[1] See 5.3.2 for comments on interpretation of tables.

[2] After 120 days only.

TABLE V-24[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE T SLEEVING IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usage see Table V-22, Sleeving Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	0.9	Normal
240 daya in VV-I-530 fluid	0	25±5	5.2	No observable change
		90	6.9	Color had leached out
	13,200	25±5	6.8	No observable change
		90	6.4	Color had leached out
240 daya in MIL-H-6083C fluid	0	25±5	5.7	No observable change
		90	8.2	Color had leached out
	13,200	25±5	6.3	No observable change
		90	6.3	Had turned darker in color
240 daya in 1 cSt silicone fluid	0	25±5	4.8	No observable change
		90	4.0	No obaervable change
	13,200	25±5	4.6	No observable change
		90	5.0	No observable change
(1) See 5.3.2 for comments on interpretation of tables.				

TABLE V-25[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE U SLEEVING IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usage see Table V-22, Sleeving Application Guide

Medium and Time of Exposure	Exposure Presaure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	6.8	Normal
240 daya in VV-I-530 fluid	0	25±5	13.9	Shrunken and stiff
		90	13.8	Shrunken, stiff, and brittle
	13,200	25±5	14.5	Shrunken and stiff
		90	12.5	Shrunken and stiff
240 days in MIL-H-6083C fluid	0	25±5	12.1	Shrunken and stiff
		90	13.2	Shrunken and stiff
	13,200	25±5	14.5	Stiff
		90	14.0	Shrunken and stiff
240 days in 1 cSt silicone fluid	0	25±5	9.9	Shrunken and stiff
		90	(2)	Shrunken, stiff, and brittle; cracks and peels if bent
	13,200	25±5	13.4	Stiff
		90	13.4	Stiff

(1) See 5.3.2 for comments on interpretation of tables.

(2) Physical properties had deteriorated too much to permit a breakdown voltage measurement.

TABLE V-26[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE V SLEEVING IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usage see Table V-22, Sleeving Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	1.5	Normal
240 days in VV-I-530 fluid	0	25±5	1.7	Shrunken
		90	1.3	No observable change
	13,200	25±5	1.3	No observable change
		90	1.3	Color had darkened
240 days in MIL-H-6083C fluid	0	25±5	0.9	No observable change
		90	1.3	Some tendency to shrink
	13,200	25±5	1.3	Color had darkened
		90	1.3	Color had darkened
240 days in 1 cSt silicone fluid	0	25±5	1.3	No observable change
		90	1.3	No observable change
	13,200	25±5	1.3	No observable change
		90	1.3	Slight tendency toward shrinking and stiffening

[1] See 5.3.2 for comments on interpretation of tables

TABLE V-27[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE W SLEEVING IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE
(For Recommended Usage see Table V-22, Sleeving Application Guide)

Medium and Time of Exposure	Exposure Pressure PSIG	Exposure Temperature °C	Dielectric Breakdown Voltage, KV, Average of 3 Measurements	Visual Examination
Air, initial condition	0	25±5	8.2	Normal
240 days in VV-I-530 fluid	0	25±5	10.7	No observable change
		90	11.3	No observable change
	13,200	25±5	11.3	No observable change
		90	10.8	Soft
240 days in MIL-H-6083C fluid	0	25±5	13.8	No observable change
		90	16.4	Swollen and yellowed
	13,200	25±5	11.5	No observable change
		90	(2)	Completely disintegrated
240 days in 1 cSt silicone fluid	0	25±5	9.0	No observable change
		90	13.6	Soft, splitting, and cracking
	13,200	25±5	9.8	No observable change
		90	(2)	Completely disintegrated

[1] See 5.3.2 for comments on interpretation of tables.
[2] Sleeving had deteriorated completely making breakdown voltage measurement impossible.

5.8 DIFFERENCE IN PERFORMANCE BETWEEN SOLID AND COATED OR
     IMPREGNATED FORMS OF POLYTETRAFLUORETHYLENE (POLY-TFE)
     POLYMER

Tables V-18 and V-25 show, respectively, that poly-TFE
(Code P) lead wire insulation (per MIL-I-003190C) was not notice-
ably affected by either silicone or petroleum base fluids, while
Code U sleeving (poly-TFE-impregnated glass braid) was severely
attacked by both types of fluids. It is also noted in appendix
B that poly-TFE coated glass cloth (sheet insulation, item 3)
was severely attacked by a petroleum base fluid. In order to
avoid confusion with this material it should be noted that poly-
TFE, although readily softened and/or removed by pressure com-
pensating fluids in the coated or impregnated forms on glass, is
not appreciably affected in the solid (such as extruded tubing)
form.

5.9 LAMINATES

Navy usage of electrically insulating laminates in air
environments is governed by Military Specifications MIL-P-79C,
MIL-P-997D, MIL-P-15037E, and MIL-P-18177C.* Although the
evaluation program at this Center did not include laminates,
some conclusions can be drawn from practical operating experience
with one particular product, Code AE laminate, a melamine-glass
material conforming to MIL-P-15037E. It is used on various
mechanical circuit interrupters, including the two shown in
figures III-2 and III-3 in Chapter III, on DSVs TURTLE and
SEACLIFF. Some of these devices have been in almost continuous
service for the past 7 years (1969-1976) in 1 cSt silicone fluid
at depths to 6500 feet (3000 psi pressure) and have shown no
signs of being affected by the fluid. The maximum or typical
temperatures of the fluid during this period are not known.
Several of these devices have also been subjected to immersion
in MIL-H-6083C fluid in laboratory evaluations for as long as 3
to 4 weeks, at pressures alternating between atmospheric and
13,500 psi, at room temperature with no signs of interaction
with the fluid. The Code AE laminate (or probably any other
melamine laminate conforming to MIL-P-15037E) can be recommended
for general use in pressure-compensating systems. On the other
hand, silicone resin laminates would not be recommended in light
of the poor performance of other silicone insulations in this
Center's evaluation program.

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*See footnote on page V-11.

5.10 MOLDING COMPOUNDS

5.10.1 Materials Evaluated

Thermosetting plastic molding compounds in general (not limited to electrical applications) for naval use in air environments are governed by Military Specification MIL-M-14G,* which supersedes MIL-M-14F (15 January 1960), MIL-P-19833B (6 August 1963), and MIL-M-21556 (30 September 1958). In the DOT program at this Center two proprietary molding compositions conforming to MIL-M-14G were selected for evaluation. Table V-28 identifies the two molding compounds by code letters and indicates the chemical types and classifications under the specification.

TABLE V-28
MOLDING COMPOUNDS EVALUATED UNDER DOT PROGRAM

Product	Chemical Type	Type Under MIL-M-14G
Code Y	Diallyl phthalate, glass fiber filled	GDI-30F
Code Z	Alkyd, glass fiber filled	MAI-60

5.10.2 Method of Evaluation

See Chapter IV, 4.9.5. Note that molding compounds were evaluated only by measuring the effect on dimensions of immersion in the evaluation fluids. This in turn relates to possible deterioration of physical integrity and dielectric quality.

5.10.3 Ratings of Molding Compounds for Deep-Submergence Use

Recommendations are given in table V-29. Detailed data on dimensional changes resulting from immersion in the three evaluation fluids are presented in tables V-30 and V-31. Dimensional changes are less than 0.5% in most cases. Where changes could be detected, there is a fairly consistent increase in dimensions at 90° C and 0 psig and a decrease at 90° C and 13,200 psi. For the present these or equivalent products conforming to MIL-M-14G, types GDI-30F and MAI-60, respectively, must be considered the preferred molding compounds for deep-submergence use in pressure-compensating fluids. Other materials of interest in future evaluations include phenolics, polyesters, melamines, and silicones, especially those conforming to MIL-M-14G.

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*See footnote on page V-3.

TABLE V-29
MOLDING COMPOUND APPLICATION GUIDE
FOR DEEP-SUBMERGENCE USE

Product	Chemical Type	Deep-Submergence Applicability in Pressure-Compensating Fluids at Temperatures to 90° C and Pressures to 13,200 psi
Code Y	Diallyl phthalate, glass fiber filled	Satisfactory for use in petroleum base and silicone fluids
Type Z	Alkyd, glass fiber filled	Satisfactory for use in petroleum base and silicone fluids

TABLE V-30[1]

DETAILED RESULTS OF 240-DAY IMMERSION OF CODE Y
MOLDED RESIN COMPOSITION IN THREE DOT FLUIDS AT
0 AND 13,200 PSIG PRESSURE[2]
(For Recommended Usage see Table V-29,
Molding Compound Application Guide)

Fluid	0 PSIG, Linear Dimension, in.						13,200 PSIG, Linear Dimension, in.					
	Room Temperature			90° C			Room Temperature			90° C		
	Sample	Before Immersion	After 240 Hr Immersion	Sample	Before Immersion	After 240 Hr Immersion	Sample	Before Immersion	After 240 Hr Immersion	Sample	Before Immersion	After 240 Hr Immersion
VV-I-530	1	0.497	0.497	1	0.502	0.503	1	0.509	0.510	1	0.500	0.496
	2	0.502	0.503	2	0.501	0.502	2	0.503	0.503	2	0.501	0.499
	3	0.496	0.496	3	0.490	0.496	3	0.503	0.503	3	0.500	0.498
MIL-H-6083C	1	0.500	0.500	1	0.500	0.501	1	0.501	0.500	1	0.501	0.499
	2	0.501	0.501	2	0.511	0.511	2	0.499	0.498	2	0.499	0.496
	3	0.504	0.504	3	0.501	0.501	3	0.510	0.510	3	0.502	0.499
1 cSt Silicone	1	0.502	0.503	1	0.503	0.503	1	0.503	0.502	1	0.493	0.490
	2	0.502	0.502	2	0.503	0.503	2	0.499	0.498	2	0.509	0.509
	3	0.503	0.503	3	0.499	0.501	3	0.528	0.528	3	0.501	0.499

[1] See 5.3.2 for comments on interpretation of tables.

[2] No change in physical condition such as softening, discoloration, etc., was observed on visual examination in any of the samples evaluated.

TABLE V-31[1]
DETAILED RESULTS OF 240-DAY IMMERSION OF CODE Z MOLDED RESIN COMPOSITION IN THREE DOT FLUIDS AT 0 AND 13,200 PSIG PRESSURE[2]
(For Recommended Usage see Table V-29, Molding Compound Application Guide)

| Fluid | 0 PSIG, Linear Dimension, in. | | | | | | 13,200 PSIG, Linear Dimension, in. | | | | | |
| | Room Temperature | | | 90° C | | | Room Temperature | | | 90° C | | |
	Sample	Before Immersion	After 240 Hr Immersion	Sample	Before Immersion	After 240 Hr Immersion	Sample	Before Immersion	After 240 Hr Immersion	Sample	Before Immersion	After 240 Hr Immersion
VV-I-530	1	0.498	0.499	1	0.512	0.512	1	0.498[3]	0.489	1	0.503	0.502
	2	0.503	0.503	2	0.500	0.500	2	0.512	0.512	2	0.516	0.516
	3	0.500	0.500	3	0.49	0.498	3	0.483	0.483	3	0.500	0.500
MIL-H-6083C	1	0.499	0.498	1	0.501	0.502	1	0.500	0.499	1	0.500	0.500
	2	0.498	0.498	2	0.509	0.508	2	0.501	0.501	2	0.503	0.504
	3	0.503	0.503	3	0.498	0.498	3	0.500	0.501	3	0.485	0.484
1 cSt Silicone	1	0.514	0.515	1	0.510	0.510	1	0.502	0.502	1	0.483	0.483
	2	0.500	0.500	2	0.500	0.501	2	0.502	0.502	2	0.501	0.501
	3	0.500	0.500	3	0.499	0.499	3	0.498	0.498	3	0.472	0.471

(1) See 5.3.2 for comments on interpretation of tables.

(2) No change in physical condition such as softening, discoloration, etc. was observed on visual examination in any of the samples evaluated.

(3) Possible error in recording the measurement.

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APPENDIX B

TYPICAL APPLICATIONS OF INSULATING MATERIALS
IN FLUID - IMMERSED ELECTRIC MOTORS

Material	Application	Comments
Magnet Wire Film 1. Polyimide (Code B) film		Good choice of film for all applications listed.
a. With silicone-modified polyester (Code AF) varnish	Rotor and stator windings of d-c drive motor in MIL-H-5605B fluid	May be a poor choice of varnish because of generally poor results with silicone materials reported in this handbook. No effect of fluid on windings was observed after 300 hours operation at a fluid temperature probably not exceeding 150° F. However, this varnish was later replaced by Code AG varnish referred to in "b" below.
b. With phenolic-modified polyester (Code AG) varnish	Rotor and stator windings of d-c drive motor in MIL-H-5606B fluid	No estimate can be made on the suitability of this varnish from presently available data.[1]
c. With oil-base phenolic (Code AJ) varnish	Canned stator of seawater flooded a-c induction motor filled with proprietary oil slurry	The varnish is believed to be similar to Code F varnish; therefore, a good choice since Code B film with Code F varnish showed the best performance of all magnet wire film varnish combinations reported in Chapter V, table V-2. After several years storage plus intermittent operation totaling <100 hours, there was no indication of insulation failure.
2. Polyvinyl formal (Code A) film with clear phenolic (Code AH) varnish	Rotor windings of d-c drive motor in Code E fluid[2]	Not a good choice of film (see Chapter V, table V-2); probably not a good choice of varnish. See comments on item 3 below. Field observations very limited.
3. Polyamide-imide (Code E) film with clear phenolic (Code AH) varnish	Stator windings of d-c drive motor in Code E fluid[2]	The film is a good choice (see table V-2) but may no longer be available. The varnish appears to be a poor choice. After 250 hours operation in Code E fluid at a maximum temperature of 140° F, the varnish was partially removed by the fluid.
4. Modified polyester base with amide-imide overcoat (Code AK) film, plus epoxy (Code K) varnish	Canned stator of seawater-flooded a-c induction motor filled with petroleum-base (Code AL) fluid	The film appears to be a good choice. It is stated by the manufacturer to be chemically identical to Code D film (see tables V-1 and V-2 in Chapter V). However, the combination of Code AK film with Code K varnish is highly questionable since this is essentially the same as Code D film plus Code K varnish which showed poor results, as reported in tables V-2 and V-6 in Chapter V); see also discussion in Chapter II, Section 2.3.4. After several years storage plus intermittent operation totaling <100 hours there has been no indication of insulation failure.
Sheet Insulation 1. Polyimide-glass cloth	Rotor slot cell insulation on d-c drive motor in MIL-H-5606B fluid	A good choice of material, except that it was observed to be too brittle and subject to cracking (not caused by the fluid) in this particular usage. It was replaced by polyamide (Code L) paper (see table V-9, in Chapter V). No effect by the fluid on the polyimide-glass was observed after 300 hours operation.
2. Polyamide paper	Rotor slot cell insulation on d-c drive motor in MIL-H-5606B fluid	Good choice for all applications listed. (1)
	Slot cell insulation, slot wedges and coil and phase separators of canned stators filled with petroleum base (Code L) fluid and with proprietary oil slurry	No indication of faulty insulation after several years storage plus intermittent operation totaling <100 hours.

Material	Application	Comments
3. Polytetrafluor-ethylene (Code P)—coated glass cloth	Rotor and stator slot cell insulation and insulation under capped end of rotor of d-c drive motor in Code E fluid[2]	Not a good choice of material. Similar to Code U glass sleeving which showed poor resistance to fluids as reported in tables V-22 and V-25. After 250 hours operation in Code E fluid at a maximum temperature of 140° F (60° C) there was extensive fraying of the glass cloth due to weakening and/or removal of the Code P coating. See Chapter V, Section 5.8.
4. Silicone resin-coated glass cloth	Banded end insulation on rotor of d-c drive motor in Code E fluid[2]	A poor choice considering generally poor results obtained with silicone materials in fluids. Fraying occurred under the same conditions as described under item 3 above.
Lead Wire Insulation		
1. Polytetrafluor-ethylene (Code P)—impregnated braided glass per MIL-W-7139[3]	Field coil connections on drive motor in MIL-H-5606B fluid	Not a good choice. Similar to Code U glass sleeving; see comments on item 3 above and discussion in Chapter V, 5.8.[1]
Sleeving		
1. Polytetrafluor-ethylene (Code P) tubing	Over field coil leads on d-c drive motor in MIL-H-5606B fluid	A good choice since this is solid (i.e., extruded) material. See discussion in Chapter V, 5.8.[1]
2. Polyester varnish-coated braided glass	1. canned stator of seawater flooded a-c induction motor, filled with proprietary oil slurry	No estimate can be made of the suitability of this material from presently available limited data. There has been no indication of insulation failure after several years storage plus intermittent operation totaling <100 hours.
Laminates		
1. Glass-melamine per MIL-P-15037, type GMG[4] NEMA grade G-5	On rotor of d-c drive motor in MIL-H-5606B fluid	Probably a good choice. See Chapter V, Section 5.9.[1]
2. Glass-epoxy per MIL-P-1877, type GEB, NEMA grade G-11.	Coil separators and slot wedges of d-c drive motor in MIL-H-5606B fluid	No estimate can be made of the suitability of this laminate from presently available data. The only information on epoxy materials in this handbook is the data on epoxy (Code K) varnish (tables V-5, V-6, and V-7 of Chapter V) which showed generally poor resistance to silicone and petroleum base fluids.[1]
3. Glass-silicone NEMA grade 7	Rotor slot wedges on d-c drive motor in Code E fluid[2]	Not a good choice considering generally poor results with silicone materials reported in this handbook. Apparent attack by fluid on resin was observed after 300 hours operation at a fluid temperature not exceeding 150° F.

[1] No reliable field data has been obtained to date. The motor has been operating satisfactorily for several years in MIL-H-5606B fluid on a deep submersible.

[2] McQuaid, R. L. and C. L. Brown, "Handbook of Fluids and Lubricants for Deep Ocean Applications," NSRDC Rept MATLAB 360, p. III-137 (1972)

[3] Now superseded by MIL-W-22759D (1976)

[4] Now superseded by MIL-P-15037E, type GME (1976)

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